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**Report of Noise Impacts at**
**Cincinnati Music Hall Resulting From The**

# FC Cincinnati Stadium Environmental Noise Model

**Prepared for:**
CINCINNATI ARTS ASSOCIATION
Cincinnati, Ohio

CINCINNATI SYMPHONY ORCHESTRA
CINCINNATI OPERA
CINCINNATI BALLET
MAY FESTIVAL

**Akustiks Project #18-0780**
**9 April 2019**

93 North Main Street | Suite 2 | Norwalk, CT 06854 203.299.1904 akustiks.com

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9 April 2019

Mr. Stephen A. Loftin
Cincinnati Arts Association
1241 Elm Street
Cincinnati Ohio 45202

Re: FC Cincinnati Stadium Noise Impact Study
AKS Project #18-0780

Dear Steve,

Enclosed is a revision of our report documenting the results of an environmental noise model that we have prepared to assess the impact of the planned new FC Cincinnati Stadium on Music Hall. This will allow the Cincinnati Arts Association and the resident companies at Music Hall to understand if and how their operations in Music Hall would be affected by events at the new stadium.

This report includes an executive summary, an outline of the study methodology, and a detailed discussion of the results. The report also includes a discussion of potential mitigation strategies at both Music Hall and in the Stadium for the negative impacts discovered in the study.

I hope that you find the enclosed to be both informative and interesting. Please call me if you have any questions or need elaboration on any aspect of the report.

Sincerely,

Paul H Scarbrough

Paul H. Scarbrough
Principal

93 North Main Street | Suite 2 | Norwalk, CT 06854 203.299.1904 akustiks.com

**FC Cincinnati Stadium Noise Impact Study**

Akustiks, LLC ("Akustiks") was engaged by the Cincinnati Arts Association to prepare an environmental noise model of the neighbourhood around the planned FC Cincinnati Stadium in the West End portion of downtown Cincinnati. The fundamental purpose of this model was to assess whether stadium operations would have a negative impact on rehearsals, performances and other activities in Music Hall.

In summary, the scope of work included the following elements:

1.01 Gather information about the existing ambient noise environment in the area of Music Hall and the new stadium.

1.02 Gather information about the physical environment, including topography, existing structures, the designs for the new stadium and its key features.

1.03 Construct a computer environmental noise model of the stadium and its environs.

1.04 Project the impact of stadium operations on the community with a specific emphasis on Cincinnati Music Hall. This will include normal operations of the FC Cincinnati Stadium as well as potential use of the stadium for high-level amplified contemporary music concerts.

1.05 To the degree that negative impacts on Music Hall are identified by the study, explore whether there are reasonable mitigation measures that could be implemented as part of the stadium design or within Music Hall.

This report includes the following sections:

1.01 An executive summary offering a high-level overview of the key study findings.

1.02 An outline of the methodology employed to complete the study.

1.03 A glossary of acoustical terminology used in this report.

1.04 A detailed discussion of the results from the environmental noise model.

1.05 An exploration of potential mitigation measures that could be implemented as part of the stadium design or within Music Hall (under development).

## 1.0 Executive Summary

1.01 Akustiks prepared an environmental noise model for the planned FC Cincinnati Stadium and its immediate environs, including an area sufficient to encompass the full perimeter of Cincinnati Music Hall. This model was prepared using SoundPlan, a comprehensive noise modeling software package that allows one to create a three-dimensional representation of the study area including all of the structures of interest, both existing and proposed. We then simulated three conditions:

a. A typical soccer match with a full stadium of 26,000 fans.

b. A high-level amplified contemporary music concert with the stage positioned at the north end of the field facing to the south.

c. A high-level amplified contemporary music concert with the stage positioned at the south end of the field facing to the north.

1.02 Model results revealed the following impacts on Springer Auditorium:

a. Crowd noise from soccer matches will be readily audible in Springer Auditorium. The model predicts that at its peak (fans responding to a home team goal, for example), crowd noise will exceed the background noise in Music Hall by between as much as 12 dB at some frequencies. This noise would be readily audible by the audience and the performers and would interfere with the subtle moments of performances by the resident companies.

b. Both the audio and crowd noise from high-level amplified contemporary music concerts would be audible in Springer Auditorium. Unlike the crowd noise impacts from soccer matches, which are focused on mid and high frequencies (i.e., the peak of the human vocal range), the impacts from amplified concerts in the stadium would be evident across much of the frequency range. The impacts are greatest when the stage is positioned at the north end of the field facing toward the south (i.e., toward Music Hall) In this scenario, at very low frequencies (the octave bands at 63 Hz. and 125 Hz.), the intrusion would be between 11 and 15 dB higher than the background noise in Springer. This would be readily audible by the audience and the performers and would prove disruptive to both rehearsals and performances.

1.03 Model results revealed the following impacts on the May Festival Chorus Rehearsal Room:

a. It appears that crowd noise from soccer matches would not be audible in the Rehearsal Room. The Rehearsal Room features more robust sound isolation to the exterior and this reduces the amount of exterior sound that penetrates to the interior. The space also has a higher background noise level (from HVAC systems) that serves to mask some intrusive noise and render it harder to hear. The intrusion from crowd noise appears to be at least 10 dB below the background noise in the Rehearsal Room, which generally renders an intrusive noise inaudible.

b. With high-level amplified contemporary music concerts, impacts in the Rehearsal Room are evident in the low frequency (63 Hz. and 125 Hz.) octave bands. This means that Rehearsal Room occupants may be aware of the beat associated with concert music in the stadium. This is likely to prove disruptive to rehearsals.

1.04 Model results revealed the following impacts on the Ballroom:

a. It appears that crowd noise from soccer matches would not be audible in the Ballroom. The combination of somewhat better sound isolation characteristics, a higher background noise level and reduced levels due to shielding effects of the Springer Auditorium roof. The intrusion from crowd noise and the PA system appears to be at least 10 dB below the background noise in the Ballroom, which generally renders an intrusive noise inaudible.

b. With high-level amplified contemporary music concerts, impacts in the Ballroom are evident in the low frequency 63 Hz. octave band. This means that Ballroom occupants may be aware of the beat associated with concert music in the stadium if the occupants were not making noise of any sort. This is unlikely to prove disruptive to banquets, receptions, and other social events in the Ballroom.

1.05 Model results revealed the following impacts on the Wilks Studio:

a. Crowd noise from soccer matches will be readily audible in the Wilks Studio. The model predicts that at its peak (fans responding to a home team goal, for example), crowd noise will exceed the background noise in Wilks by between as much as 10 dB at some frequencies. This noise would be readily audible by the occupants and would interfere with both rehearsals and performances.

b. Both the audio and crowd noise from high-level amplified contemporary music concerts would be audible in the Wilks Studio. Unlike the crowd noise impacts from soccer matches, which are focused on mid and high frequencies (i.e., the peak of the human vocal range), the impacts from amplified concerts in the stadium would be evident across much of the frequency range. The impacts are greatest when the stage is positioned at the north end of the field facing toward the south (i.e., toward Music Hall) In this scenario, at very low frequencies (the octave bands at 63 Hz. and 125 Hz.), the intrusion would be 8 dB higher than the background noise in Wilks. This would be readily audible during both rehearsals and performances.

1.06 Model results revealed the following impacts on Corbett Tower:

a. It appears that crowd noise from soccer matches may be only barely audible in Corbett Tower. Corbett Tower has no direct line of sight to the Stadium and is thus well shielded from crowd noise. The space also has a higher background noise level (from HVAC systems) that serves to mask some intrusive noise and render it harder to hear.

b. With high-level amplified contemporary music concerts, impacts in Corbett Tower are evident at low frequencies (the 63 Hz. octave band). This means that Corbett Tower occupants may be aware of the beat associated with concert music in the stadium. This may be a minor annoyance during performances but should not prove especially disruptive to non-performance related uses of the space.

1.07 It is clear that mitigation will be required to address the impacts revealed in the FC Cincinnati Stadium noise impact study.

a. Mitigation Possibilities for the Stadium
One of the factors contributing to the noise intrusion projected within Music Hall is the amount of crowd noise and PA system sound that escapes over the top of the seating bowl under the roof and through other leakage points at the perimeter of the stadium.

We anticipate that a significant reduction in the radiated noise out into the community could be achieved by controlling leaks below the roof. We modeled the impact of such a modification to the stadium model, and can report that this would definitely produce a worthwhile reduction in the impact on Music Hall. It may also be necessary to treat the interior face of these enclosure walls to avoid reflecting additional sound energy through the opening in the roof over the field. This latter strategy is not reflected in the current modelling results contained herein.

b. Mitigation Possibilities for Music Hall

i) Springer Auditorium
As noted previously, the roof over Springer Auditorium is relatively lightweight, and the ceiling features a number of significant openings for theatrical lighting and rigging purposes. These combine to weaken the overall sound isolation properties of the roof and ceiling assembly as a whole. There are two possibilities for improving the isolation performance of this assembly:

- Option A would comprise building gypsum board enclosures around the various front-of-house lighting and rigging positions to protect these openings from noise that penetrates into the attic through the roof.

- Option B would involve installing a gypsum board sound isolation ceiling on the underside of the roof. Such a ceiling would comprise two or three layers of gypsum board attached to framing that is suspended on neoprene-spring isolation hangers. This option is likely to be more challenging given the steep pitch of the roof over Springer Auditorium.

ii) May Festival Chorus Rehearsal Room
It seems likely that the intrusion in the May Festival Chorus Room could be addressed by installing a gypsum board sound isolation ceiling on the underside of the roof. Such a ceiling would comprise two or three layers of gypsum board attached to framing that is suspended on neoprene-spring isolation hangers. This ceiling would be above the acoustical tile ceiling and below the roof framing in this area. HVAC ductwork should be kept below the isolation ceiling to avoid undesirable penetrations of the isolation ceiling.

iii) Ballroom
At this stage, it appears that mitigation in the Ballroom will not be required.

iv) Wilks Studio
It seems likely that the intrusion in the Wilks Studio could be addressed by installing a gypsum board sound isolation ceiling on the underside of the roof trusses. Such a ceiling would comprise two or three layers of gypsum board attached to framing that is suspended on neoprene-spring isolation hangers. HVAC ductwork should be kept below the isolation ceiling to avoid undesirable penetrations of the isolation ceiling. It will also be necessary to add an isolated wall assembly with windows along the 14th Street exterior wall of the Wilks Studio.

v) Corbett Tower
In Corbett Tower, it appears that mitigation beyond what is proposed for the Stadium may not be required. If mitigation is desired, we believe that it could be as simple as adding ¾-inch thick acoustic storm windows to the interior of the existing historic windows.

## 2.0 Definitions

In reading this report, it is important to understand certain terminology and how it is being used in this context:

2.01 Ambient Noise
Noise that is more or less continuous in a locale. In most urban environments this comprises noise from vehicular traffic, external building mechanical equipment, and other sound sources. While ambient noise levels in a particular area may rise or fall over time, they almost never disappear entirely. Ambient noise is always present, but it is not necessarily steady state.

2.02 Intrusive Noise
This refers to noise associated with non-continuous sound sources. Examples include construction activities, children in a playground, crowd noise at a sporting event, background music in an open-air bar or restaurant, and live sound associated with a performance.

2.03 dBA
Decibels (dB) measured using the A-weighting network. This is a convenient single number reference of the sound pressure level associated with a particular sound source. The A-weighting network aggregates sound levels across the full spectrum of human hearing (from low or bass frequencies to high or treble frequencies). The A-weighting network takes into consideration that at low to moderate sound levels (typically 55 dB and below) the human ear is more sensitive to mid-frequency and high frequency sound and less sensitive to low frequency sound.

2.04 dBC
Decibels (dB) measured using the C-weighting network. This is a convenient single number reference of the sound pressure level for higher-level sound sources. Like the A-weighting network, the C-weighting network aggregates sound levels across the full spectrum of human hearing (from low to high frequencies). The C-weighting network is intended for measuring high sound levels (typically 85 dB and above) where the sensitivity of the human ear is more uniform across the frequency spectrum.

2.05 Weighting Network
A schedule of values that either emphasize or de-emphasize the measured sound level in a particular range of frequencies before that level is summed with measurements in other frequency ranges. Weighting networks are used to sum sound levels so that the single number result more closely aligns with human perception of different sound levels. The table below gives these values for the A and C weighting networks defined above. A negative value is subtracted before that level is summed with other measured values. A positive value is added to the measured level before summation.

| Weighting Network | Octave Band Center Frequencies (Hz.) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 63 | 125 | 250 | 500 | 1000 | 2000 | 4000 | 8000 |
| A (dBA) | -26 | -16 | -9 | -3 | 0 | +1 | +1 | -1 |
| C (dBC) | -1 | 0 | 0 | 0 | 0 | 0 | -1 | -3 |

2.06 Dynamic Range
In music and/or speech (especially in a performance setting), the variation in sound pressure level between the softest and loudest parts of the performance or recording.

2.07 Noise Criteria
Background noise is the term acousticians use to refer to the continuous, low level of sound that is present in almost any interior environment. When analyzing or specifying background noise levels it is essential to employ a method of rating noise that compensates for the fact that the human ear is more sensitive to mid-frequency and high frequency sound than it is to low frequency sound. The Noise Criteria methodology accounts for this imbalance in the human hearing mechanism. Noise Criteria (NC) curves aggregate decibel measurements across the full frequency range of human hearing and then correlate these with subjective impressions of the overall level of background noise in a space. Each curve has a different NC rating number and represents a different noise level as perceived by the human ear. A higher rating connotes a higher perceived level of noise. Through experience and testing acousticians have determined the preferred noise criteria for different activities.

2.08 Transmission Loss
The reduction in sound level, in decibels, as sound transmits across any sort of barrier. The barrier can be a single material or a complex assembly comprising multiple materials. High sound transmission loss means that little sound is transmitted across the material or assembly. Low sound transmission loss means that a large amount of the sound is transmitted across the material or assembly.

## 3.0 Study Methodology

3.01 To prepare this assessment, Akustiks prepared a model of the site using SoundPlan, a sophisticated noise modeling and mapping software package. The model is a three-dimensional digital representation of the site including the entire built environment, both existing and proposed. Layered onto this representation are the various noise sources at the site: traffic and, in this case, the amplified sound associated with FC Cincinnati Stadium events. The model then projects the noise levels throughout the site, allowing us to understand how events in the stadium will impact the environs.

3.02 The following source documents were used in the preparation of the SoundPlan model:

a. Site plans and a three-dimensional architectural model of the proposed FC Cincinnati Stadium supplied by the FC Cincinnati design team. The area modeled extends from above West Liberty Street on the north, to the region of Jones Street on the west, the region of Grant Street to the south and midway across Washington Park on the east.

b. Information on the key stadium construction materials supplied by the FC Cincinnati design team. We used manufacturer transmission loss data for materials when such data was available. When such data was not available, we calculated the transmission loss performance of the materials using Insul, an industry standard software package for modeling the performance of materials and construction assemblies.

c. Information on existing building locations and profiles throughout the neighborhood from published online sources such as Google Earth and Google Maps.

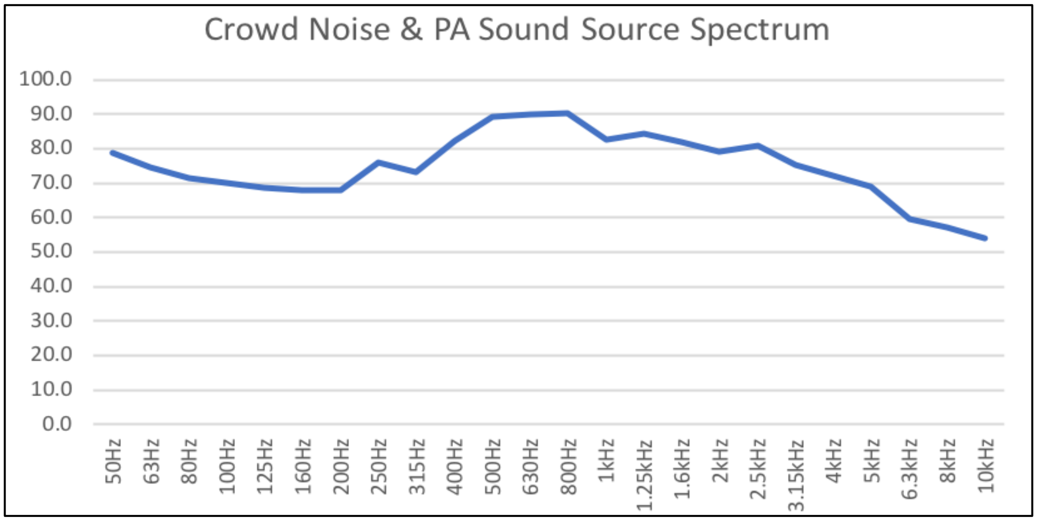
d. Data on the frequency spectrum of the male human voice at a high level of effort (shouting) from a published source by Leo L. Beranek.

e. In-house measurement data on typical third-octave band sound pressure levels at the house mix locations for large-scale contemporary music concerts. Spectra from a number of events were examined and a normalized or idealized spectrum developed for use in the model.

3.03 Once the model was complete, we modeled three different scenarios:

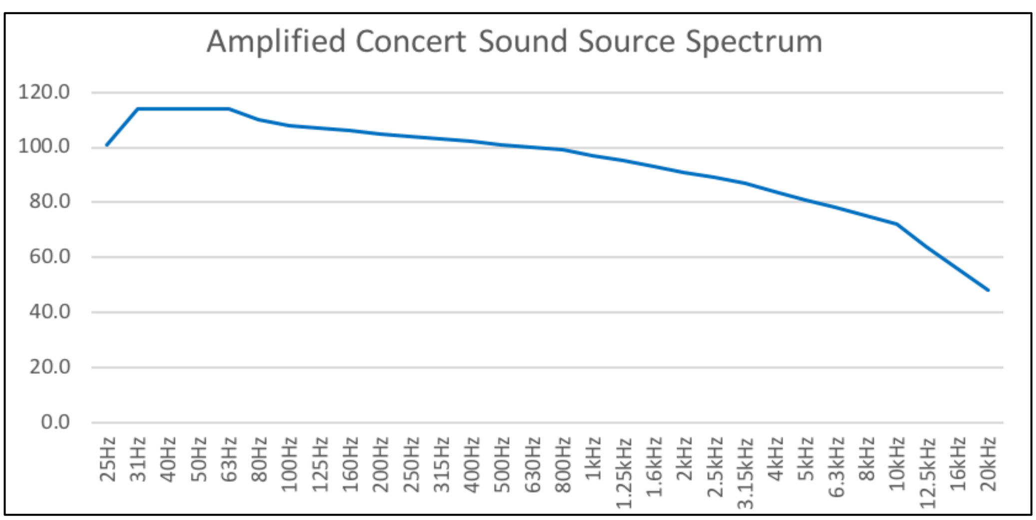
a. Scenario A: A typical soccer match. For this scenario, we assumed that the stadium was full (26,000 fans), and that 75% of the fans were cheering at a high level in response to a hometown team goal, a dramatic save by a goalie or other match event. Based upon this input, the model generated levels of approximately 105 dBA on the field, which is consistent with data measured by the FC Cincinnati AV consultant at other Major League Soccer facilities. See graph #1 below for this spectrum.

**Graph #1:** Sound source spectrum for crowd noise and stadium PA. These are sound pressure levels (referenced to 20μPa) at the perimeter of the field.




b. Scenario B: A typical highly amplified contemporary music concert. For this scenario, we placed the stage at the north end of the field and oriented it to face the south. This source produces approximately 105 dBA or 118 dBC at the house mix location, which is positioned 150-feet from the loudspeaker array at the stage. See Graph #2 below for the spectrum for this sound source.

**Graph #2:** Sound source spectrum for amplified contemporary music concert. These are sound pressure levels (referenced to 20μPa) at the house mix location, which was positioned 150-feet from the stage and loudspeaker arrays.



c. Scenario C: A typical highly amplified contemporary music concert. For this scenario, we placed the stage at the south end of the field and oriented it to face the north. The same spectrum previous described above was used for this scenario.

3.04 Crowd noise was modeled as a series of area sources, reflecting the different seating areas in the bowl. The total number of area sources is close to 50. The total surface area of the crowd sources is approximately 12,400 square meters or slightly less than 133,500 square feet. The sound power per unit area is approximately 107 dB/square meter. This was adjusted to produce a level between 100 and 105 dBA on the field, a value that was given to us by the FC Cincinnati AV consultant based upon their observations and measurements at other MLS stadiums in North America. A directivity factor was not applied to the crowd noise as the enclosure of the stands and the stadium roof will tend to contain and diffuse the resulting sound field such that it will not have a particularly strong directional character.

3.05 The sound reinforcement system employed in the concert model used the directivity patterns for an example stadium sound system supplied by d&b audiotechnik, one of the major manufacturers of line array technology for large venues. The output of this system was adjusted to produce approximately 118 dBC or 105 dBA at a house mix position located 150-feet from the stage and the main loudspeaker arrays. Crowd noise at such events was modeled in a similar fashion to that for soccer matches, with the exception that no audience members are seated to the sides and rear of the stage and an audience was assumed on the field itself.

3.06 For each scenario, we selected appropriate receiver positions on Music Hall and projected the third octave band sound pressure levels at each receiver position.

3.07 We then projected the intrusive noise impact on the interior of selected spaces within Music Hall by subtracting the amount of noise reduction that we observed at three subject areas in Music Hall, namely Springer Auditorium, the May Festival Chorus Rehearsal Room and the Ballroom. The noise reduction values were derived by operating a high-level broad band noise source (shotgun blast) on the roof and simultaneously measuring the noise levels at the roof and inside each subject space. Similar projections of intrusive noise were undertaken for the Wilks Studio and Corbett Tower by calculating the expected sound isolation performance of the exterior envelopes of these spaces.

3.08 The resulting calculated levels were then graphed against NC curves and the measured background noise in each space to assess whether the resultant levels of intrusion were likely to be audible and/or disruptive.

## 4.0 Detailed Discussion of the Results: Springer Auditorium

4.01 The results for Springer Auditorium revealed that even crowd noise by itself can be loud enough to cause intrusion in the house and on stage. This is primarily the result of the comparatively lightweight construction of the roof and the presence of many openings in the plaster ceiling of the auditorium for front of house lighting positions, canopy rigging and the old chandelier exhaust.

4.02 The other factor influencing the results in Springer Auditorium is the exceptionally quiet background noise level in the house. A key priority of the recent renovation project was to reduce excessive noise from the existing HVAC systems serving the house. This effort was successful and the observed background noise levels in Springer Auditorium are now below NC-15 and approach NC-10, world class by almost any standard.

4.03 The results graphs below illustrate the intrusion created under each scenario. In each graph, frequency is presented along the horizontal axis in octave bands from low or bass frequencies on the left side of the graph to high or treble frequencies on the right. Sound pressure level in decibels (dB) is presented on the vertical axis. The black curve at the bottom of the graph is identified as the Threshold of Hearing, the theoretical lowest level of sound that humans can hear. The light grey curves are the NC curves the were previously defined. The green line is the background noise in the subject space. Three conditions are illustrated on each graph:

a. The red line is the projected level of the scenario inside Springer Auditorium given the current design of the stadium.

b. The orange line is projected level of the scenario inside Springer Auditorium with the reduction achieved by enclosing the seating bowl up to the underside of the roof.

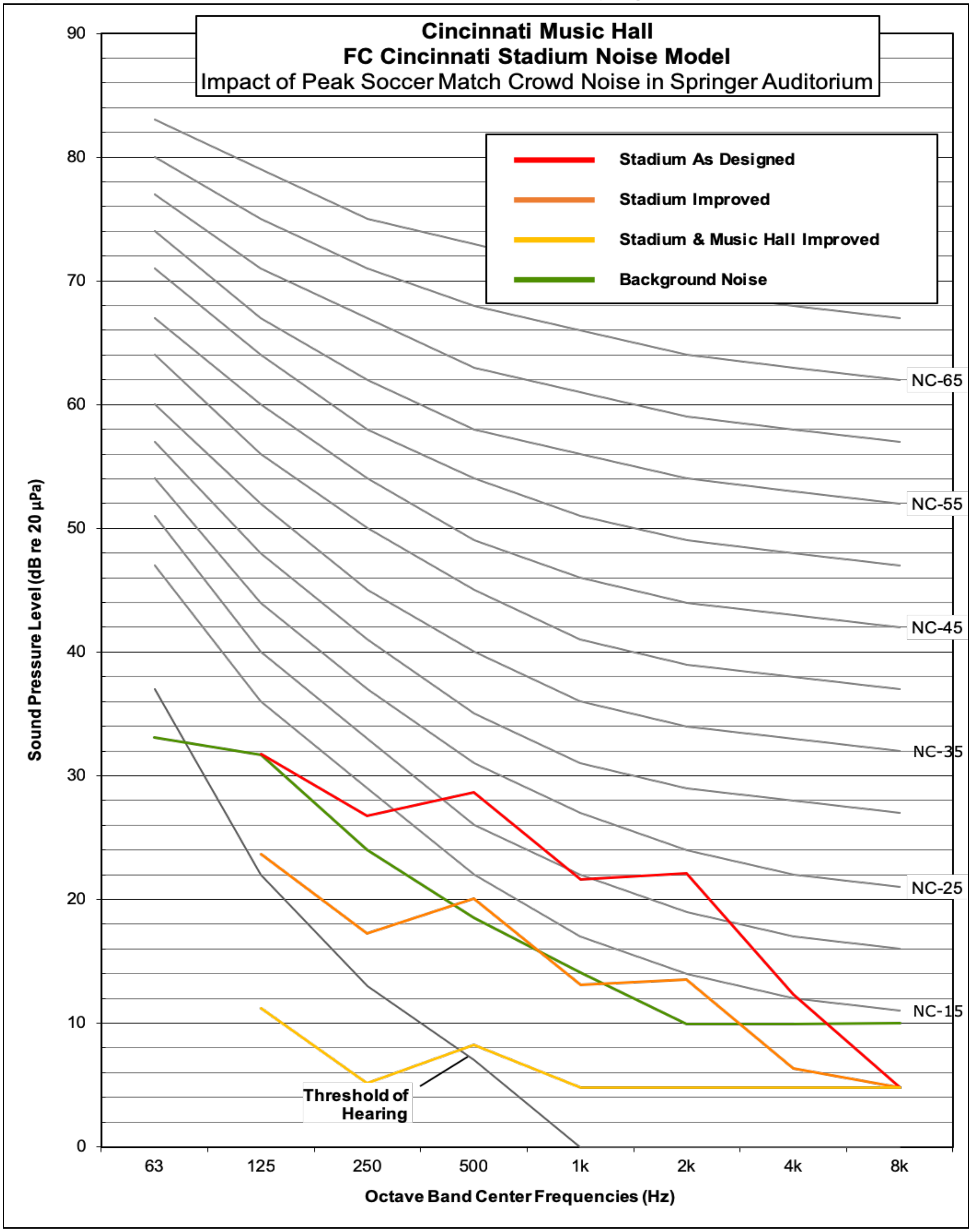
c. The yellow line is the projected level of that scenario inside Springer Auditorium with the reduction achieved by enclosing the stadium seating bowl as described above and improving the sound isolation performance of the ceiling of Springer by constructing enclosures around the openings in the ceiling.

4.04 Graph #3 illustrates the intrusion in Springer Auditorium under Scenario A.

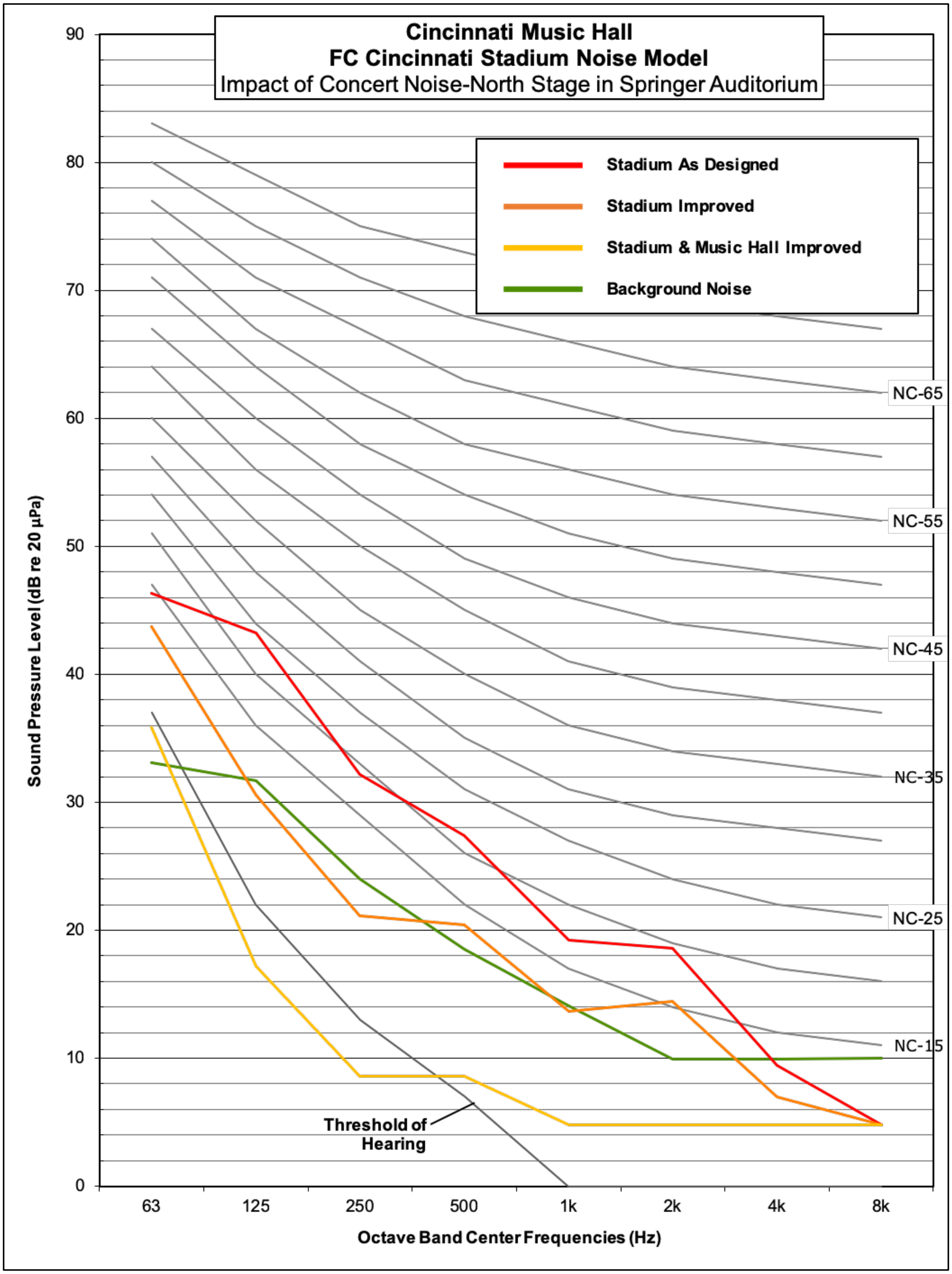
4.05 Graph #4 illustrates the intrusion in Springer Auditorium under Scenario B.

4.06 Graph #5 illustrates the intrusion in Springer Auditorium under Scenario C.

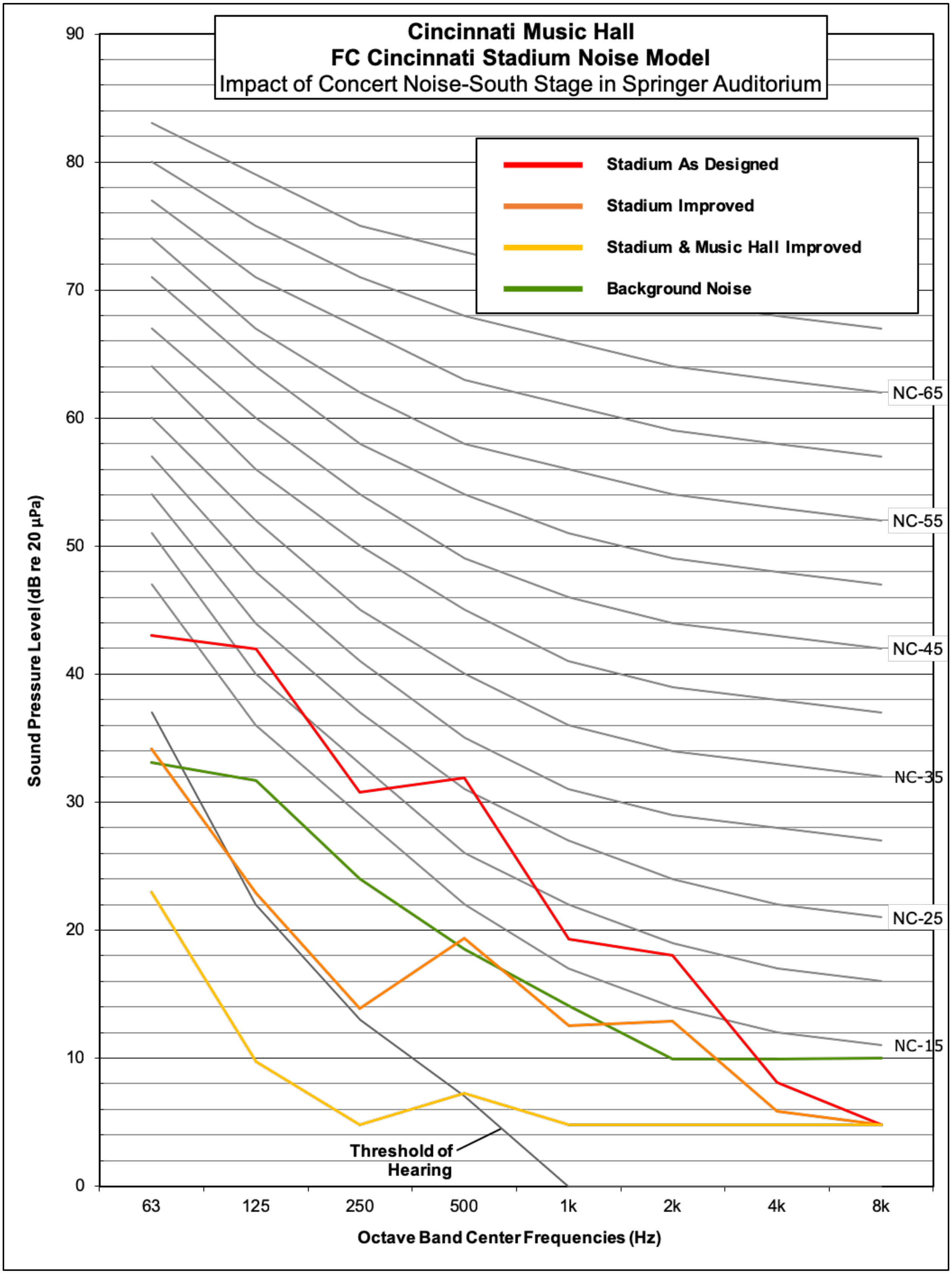
**Graph #3:** Scenario A – Crowd Noise and Stadium PA sound in Springer Auditorium



**Graph #4**: Scenario B – Concert Noise from North Stage in Springer Auditorium



**Graph #5:** Scenario C – Concert Noise from South Stage in Springer Auditorium



## 5.0 Detailed Discussion of the Results: May Festival Chorus Rehearsal Room

5.01 The results for the May Festival Chorus Rehearsal Room do not exhibit as dramatic an intrusion as that observed in Springer Auditorium. It seems likely that crowd noise at soccer games may not be audible.

5.02 One factor influencing the results in the Rehearsal Room is the comparatively high background noise level. The noise levels in the Rehearsal Room fall between NC-25 and 30, which helps mask or cover the intrusive noise from the exterior.

5.03 The graphs for the May Festival Chorus Rehearsal Room illustrate two conditions:

a. The red line is the projected level of the scenario inside the Rehearsal Room given the current design of the stadium.

b. The orange line is projected level of that scenario inside the Rehearsal Room with the reduction achieved by enclosing the stadium seating bowl up to the underside of the stadium roof.

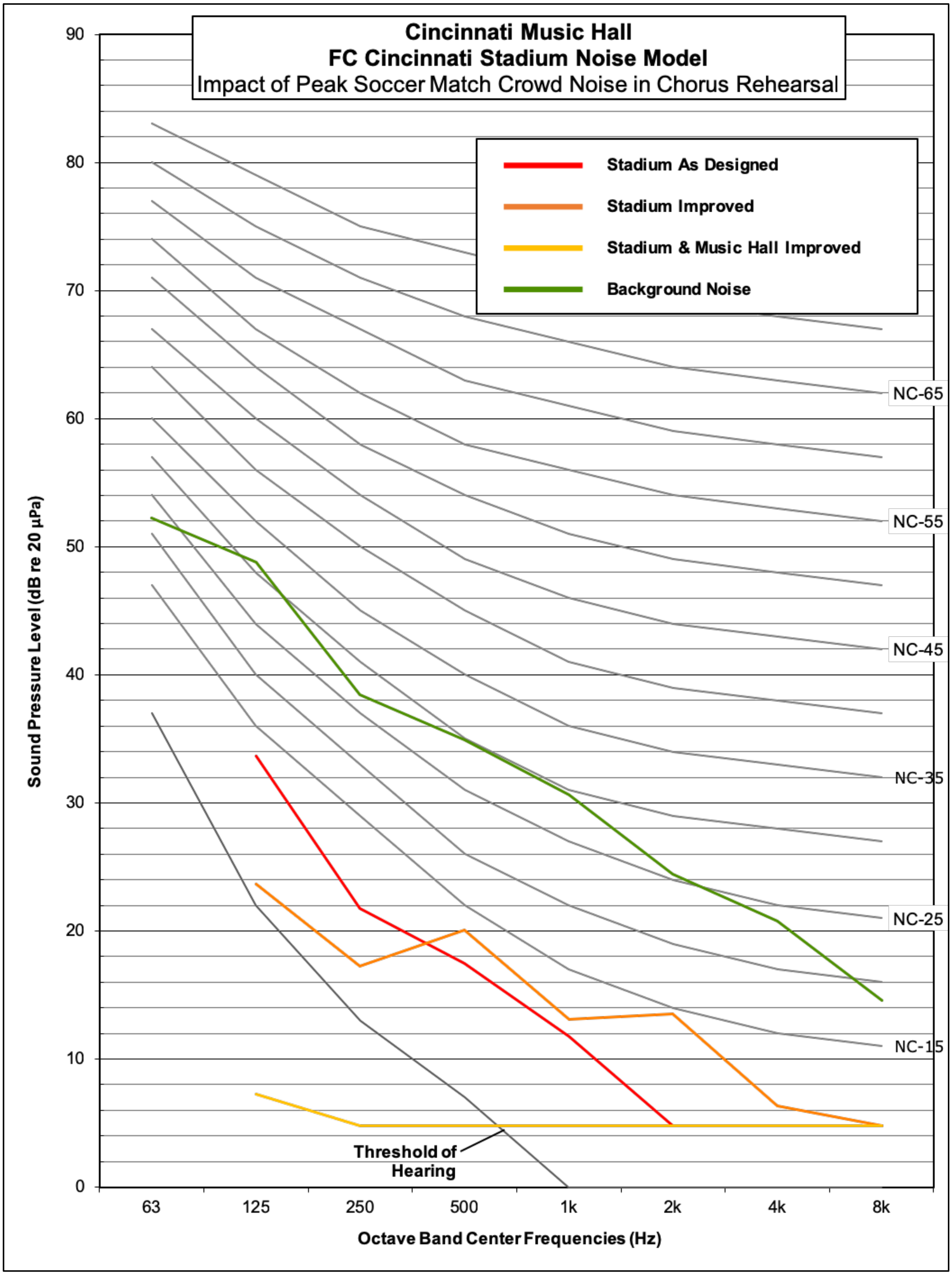
c. The yellow line is the projected level of that scenario inside the Rehearsal Room with the reduction achieved by enclosing the stadium seating bowl as described above and improving the sound isolation performance of the roof by constructing a drywall isolation ceiling in the space. It is not clear that such mitigation is absolutely required and further study of the space is recommended.

5.04 Graph #6 illustrates the intrusion in the Chorus Rehearsal Room under Scenario A.

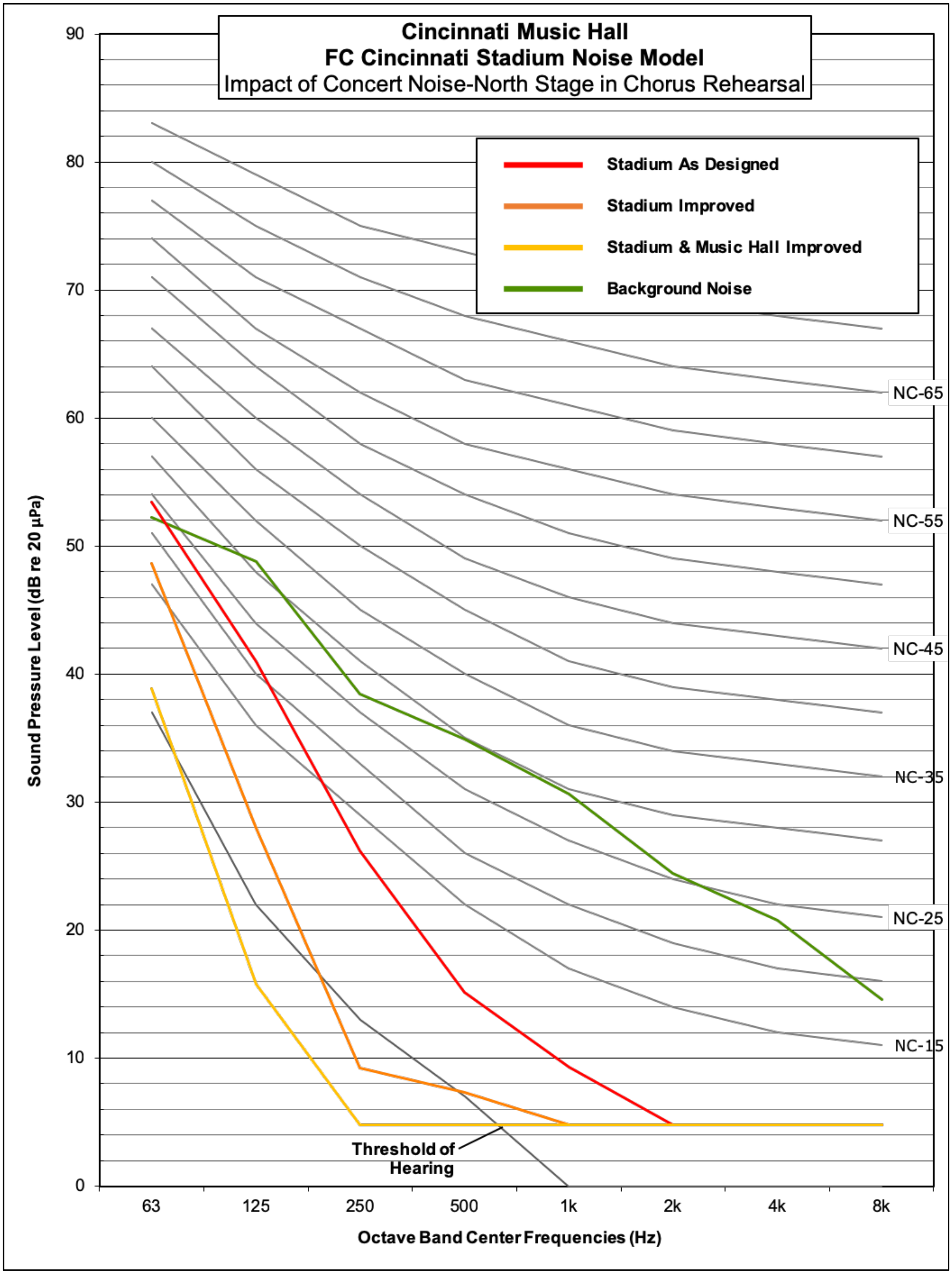
5.05 Graph #7 illustrates the intrusion in the Chorus Rehearsal Room under Scenario B.

5.06 Graph #8 illustrates the intrusion in the Chorus Rehearsal Room under Scenario C.

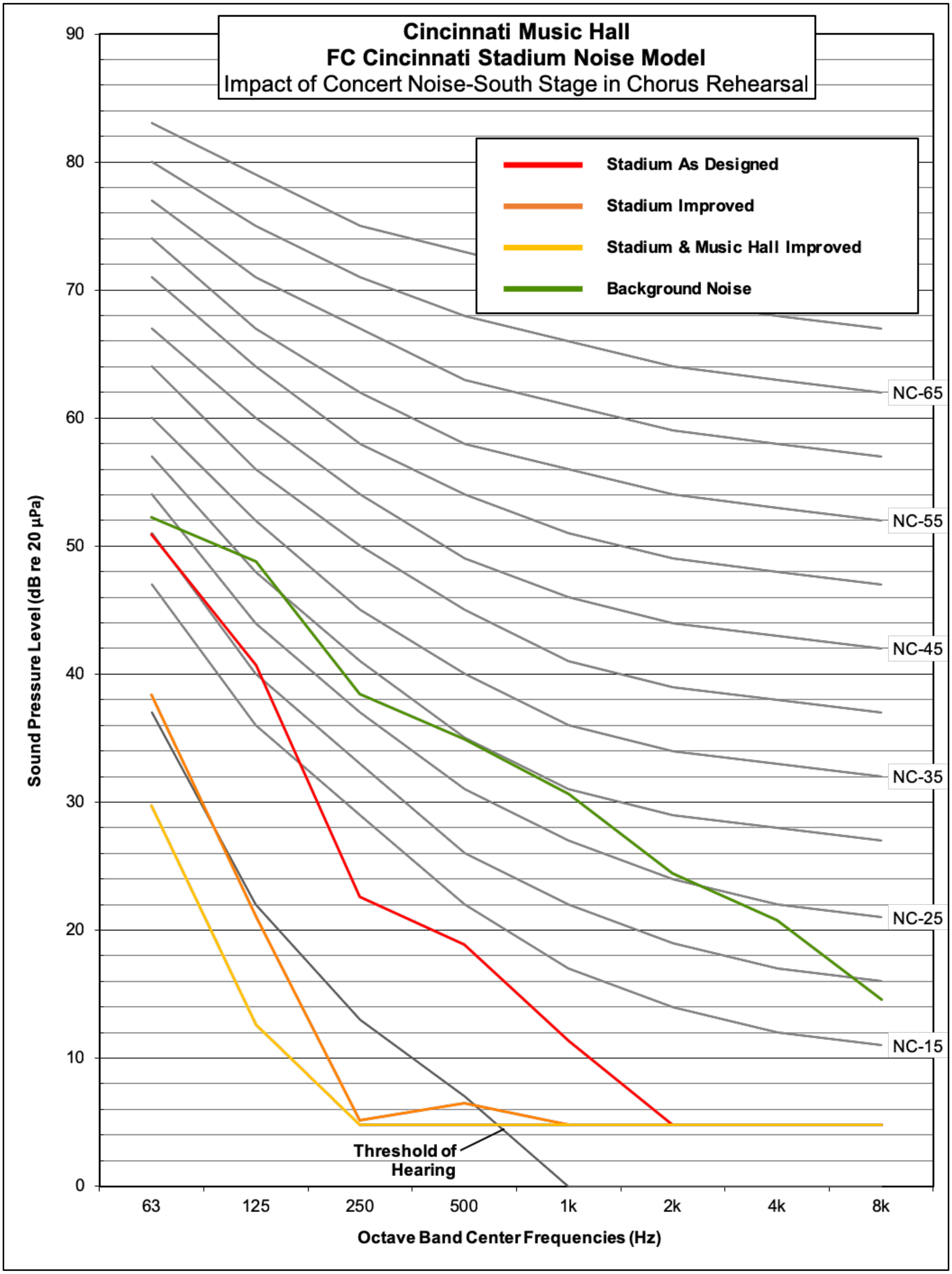
**Graph #6:** Scenario A – Crowd Noise and Stadium PA Sound in May Festival Chorus Rehearsal Room



**Graph #7:** Scenario B – Concert Noise from North Stage in May Festival Chorus Rehearsal Room



**Graph #8:** Scenario C – Concert Noise from South Stage in May Festival Chorus Rehearsal Room



## 6.0 Detailed Discussion of the Results: Ballroom

6.01 The results for the Ballroom suggest that crowd noise and PA system sound from soccer matches would not be audible in the Ballroom. The combination of somewhat better sound isolation characteristics, a higher background noise level and reduced levels due to the shielding effect of the Springer Auditorium roof.

6.02 The results also suggest that high-level amplified contemporary music concerts would only exhibit any intrusion in the low frequency 63 Hz. octave band. Ballroom occupants may be aware of the beat associated with concert music in the stadium if the Ballroom occupants were not making noise of any sort. We do not believe that this intrusion would be disruptive under most circumstances.

6.03 The graphs for the Ballroom illustrate two conditions:

a. The red line is the projected level of the scenario inside the Rehearsal Room given the current design of the stadium.

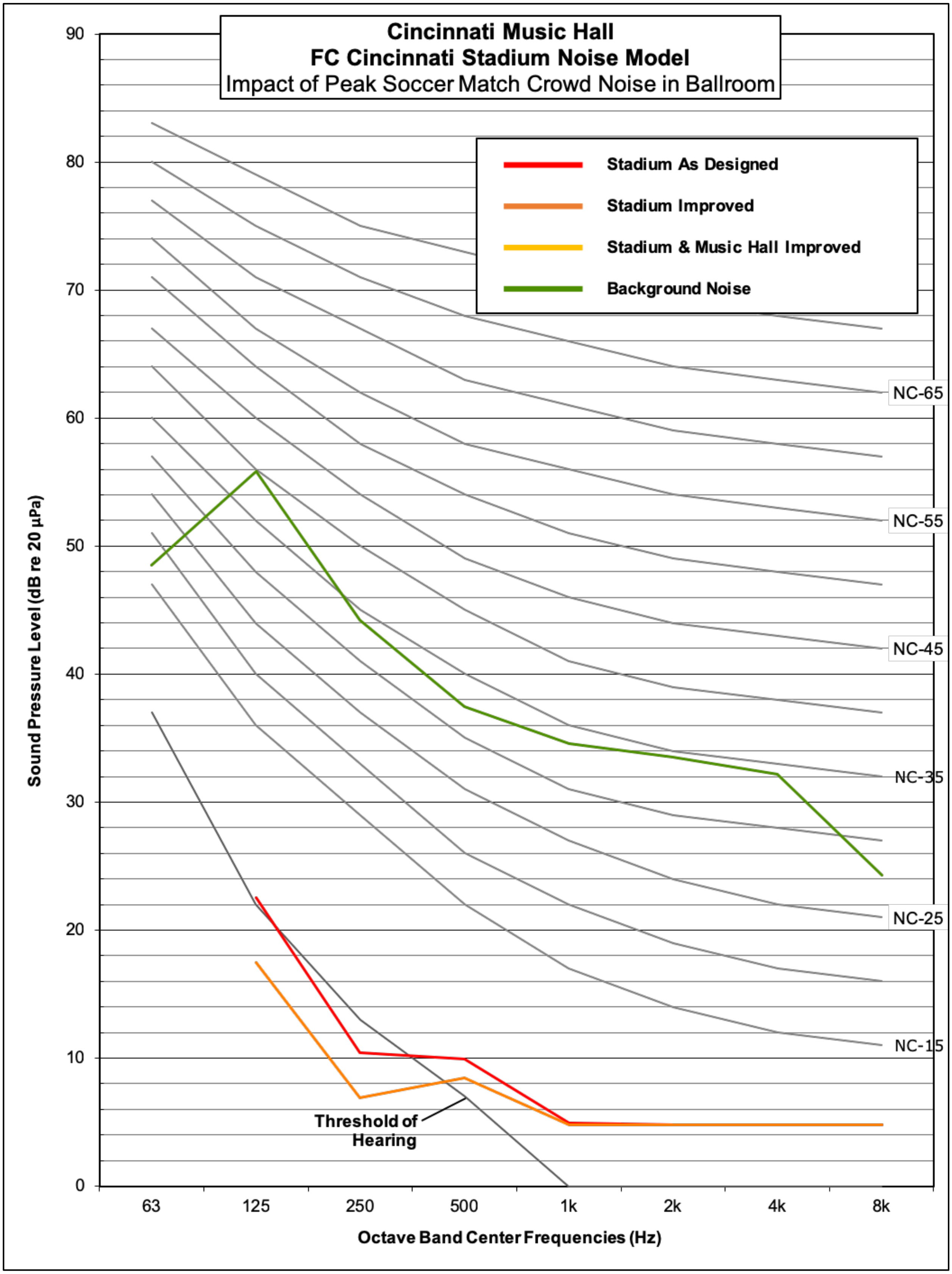
b. The orange line is projected level of that scenario inside the Rehearsal Room with the reduction achieved by enclosing the stadium seating bowl up to the underside of the stadium roof.

6.04 Graph #9 illustrates the intrusion in the Ballroom under Scenario A.

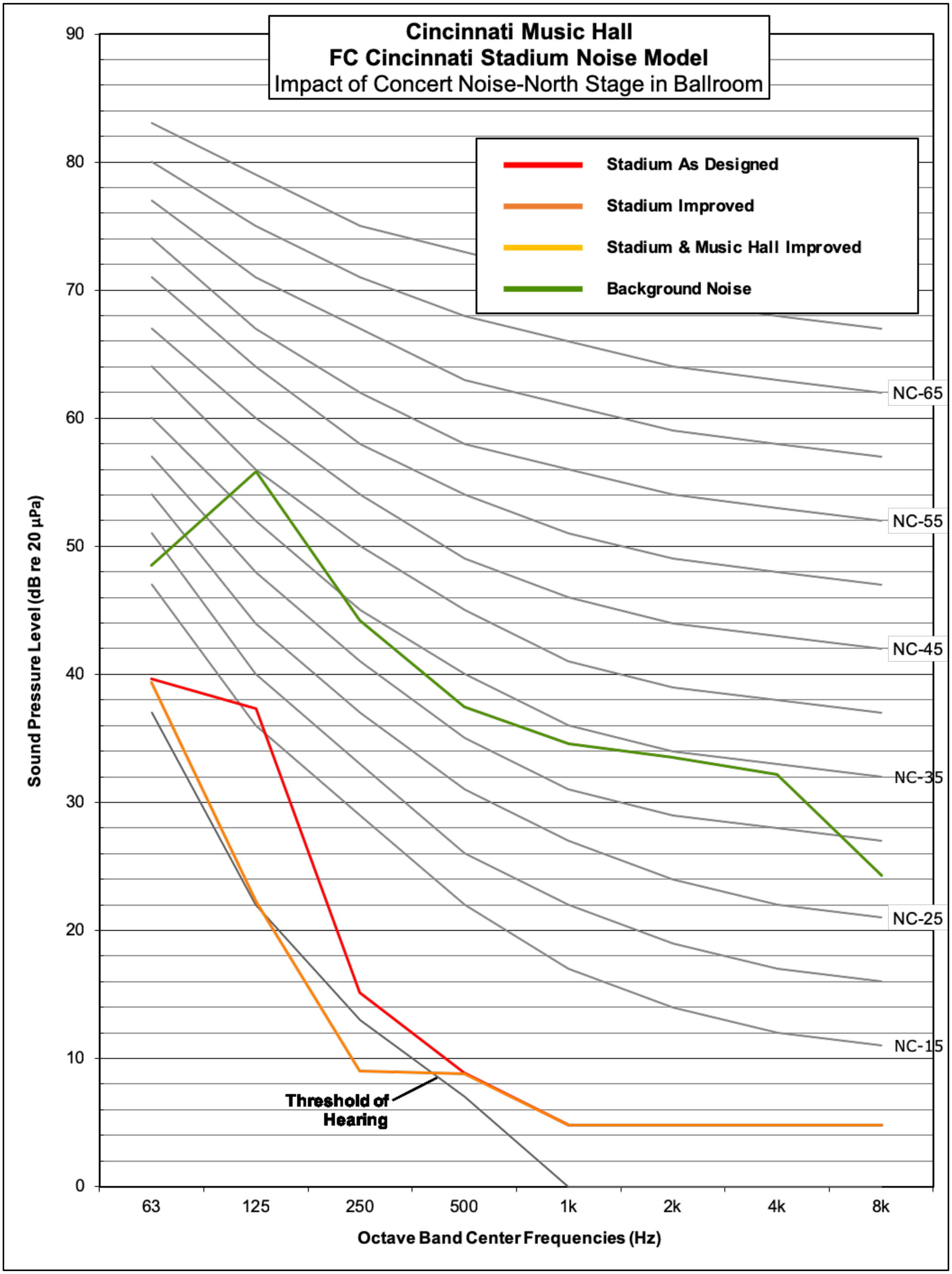
6.05 Graph #10 illustrates the intrusion in the Ballroom under Scenario B.

6.06 Graph #11 illustrates the intrusion in the Ballroom under Scenario C.

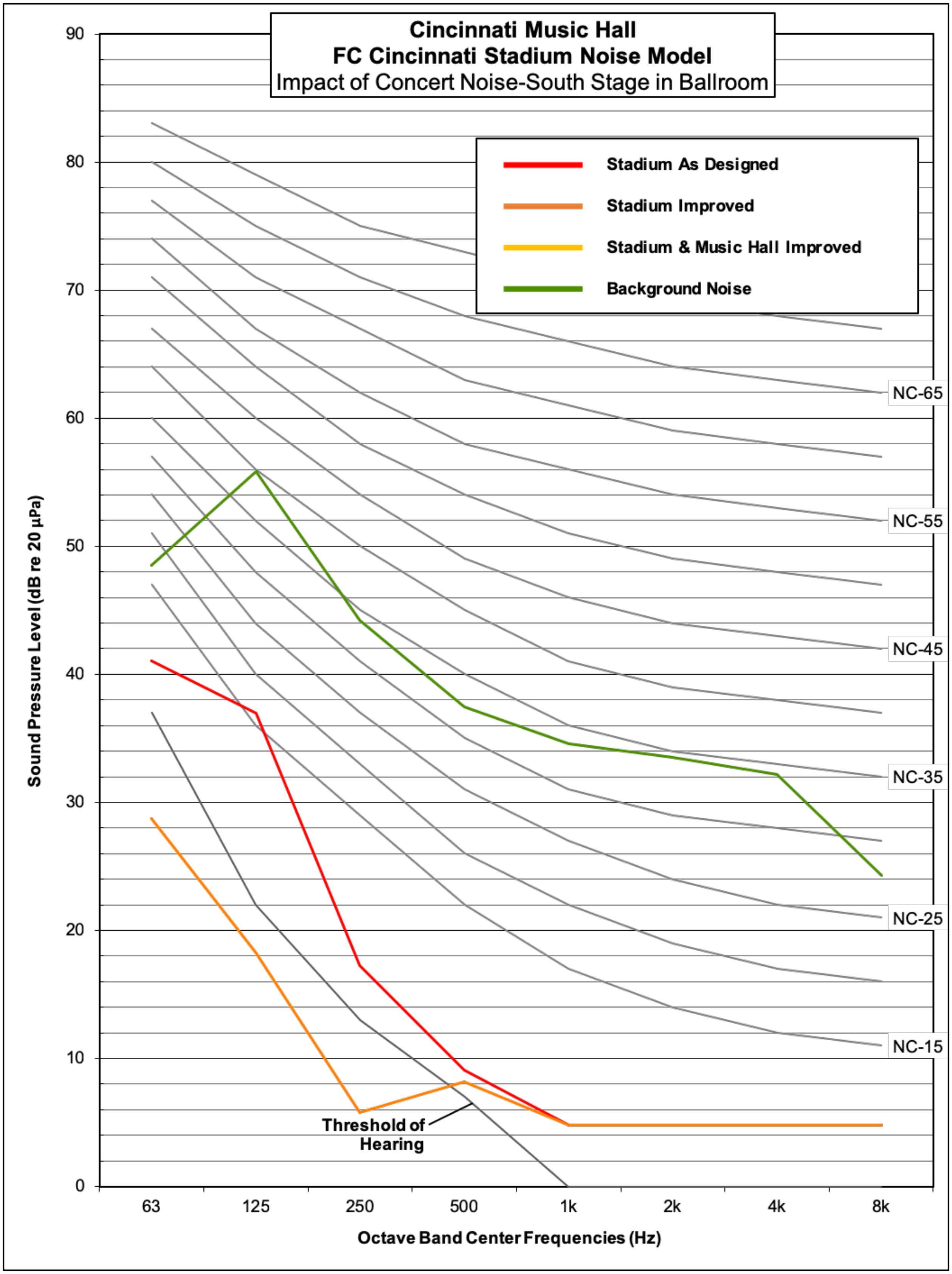
**Graph #9:** Scenario A – Crowd Noise and Stadium PA Sound in the Ballroom



**Graph #10:** Scenario B – Concert Noise from North Stage in the Ballroom



**Graph #11:** Scenario C – Concert Noise from South Stage in the Ballroom



## 7.0 Detailed Discussion of the Results: Wilks Studio

7.01 The results for the Wilks Studio suggest that crowd noise and PA system sound from soccer matches would be readily audible in the Studio. This is the result of the lightweight construction of the roof and the presence of windows overlooking $14^{th}$ Street.

7.02 The results also suggest that high-level amplified contemporary music concerts would exhibit significant intrusions in the Wilks Studio. The degree of intrusion is sufficient to be disruptive under most circumstances.

7.03 The graphs for the Wilks Studio illustrate two conditions:

a. The red line is the projected level of the scenario inside the Wilks Studio given the current design of the stadium.

b. The orange line is projected level of that scenario inside the Wilks Studio with the reduction achieved by enclosing the stadium seating bowl up to the underside of the stadium roof.

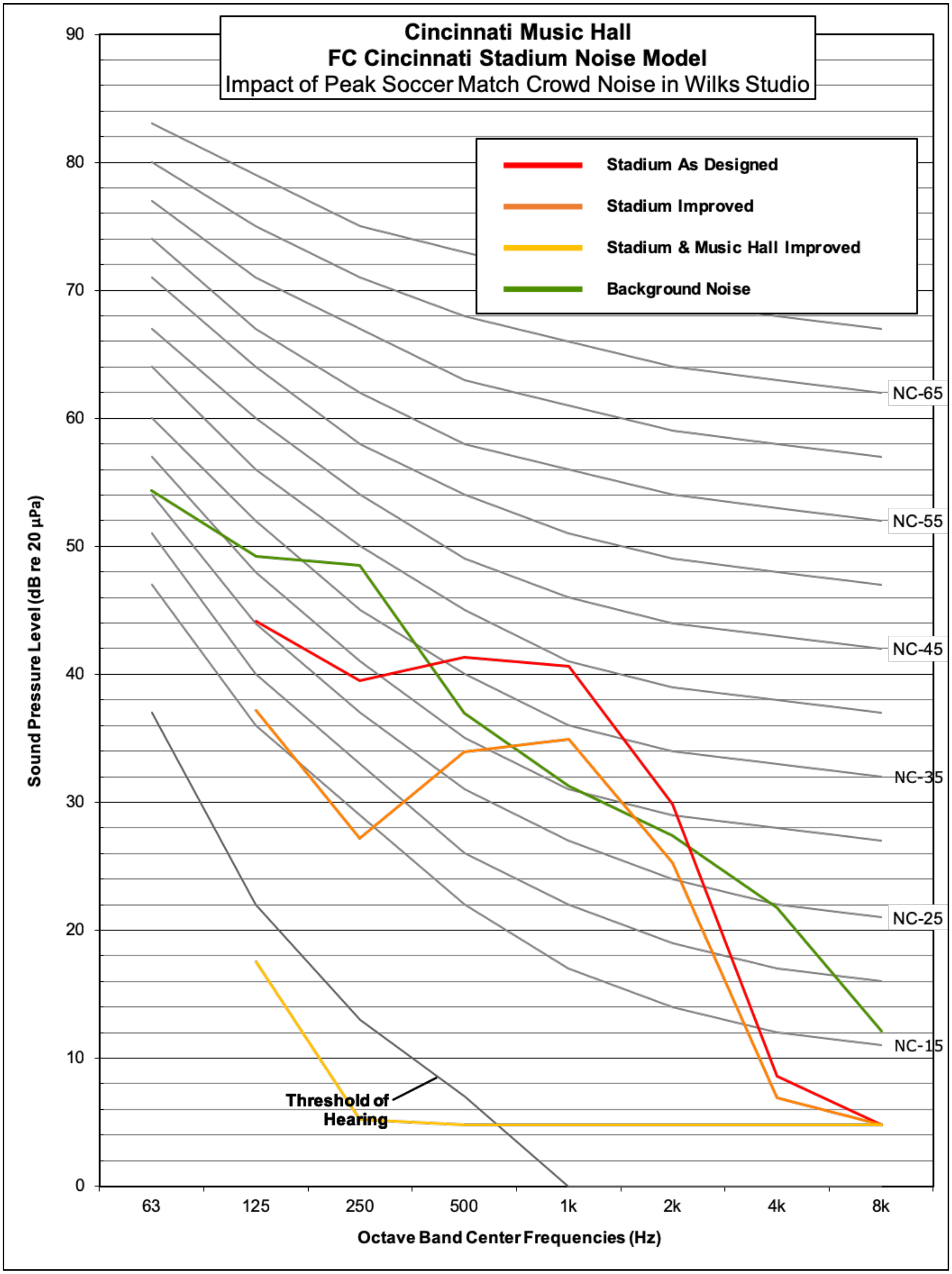
c. The yellow line is the projected level of that scenario inside the Wilks Studio with the reduction achieved by enclosing the stadium seating bowl as described above and improving the sound isolation performance of the roof by constructing a drywall isolation ceiling in the space and an isolated wall with new windows along the $14^{th}$ Street façade.

7.04 Graph #12 illustrates the intrusion in the Wilks Studio under Scenario A.

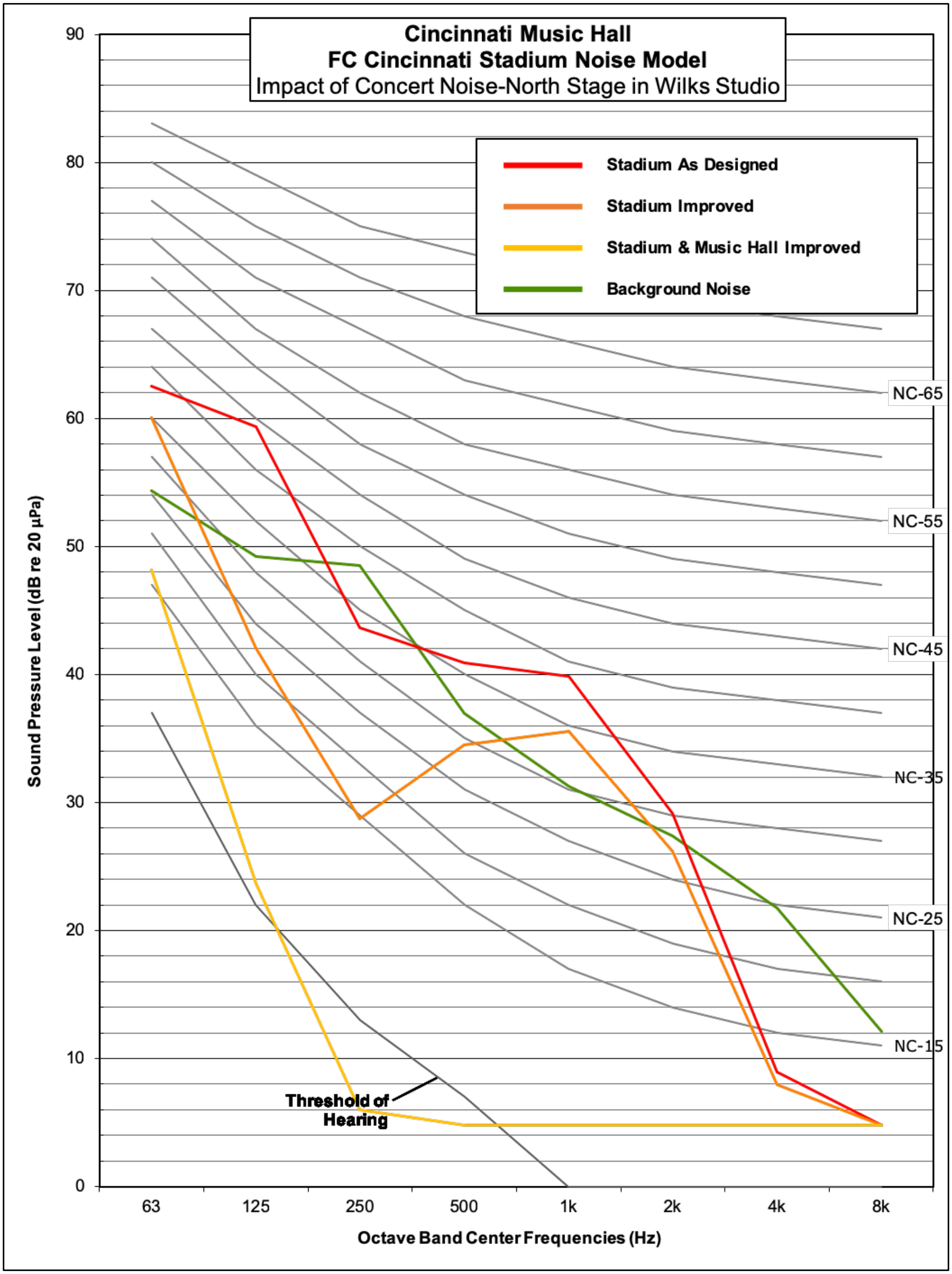
7.05 Graph #13 illustrates the intrusion in the Wilks Studio under Scenario B.

7.06 Graph #14 illustrates the intrusion in the Wilks Studio under Scenario C.

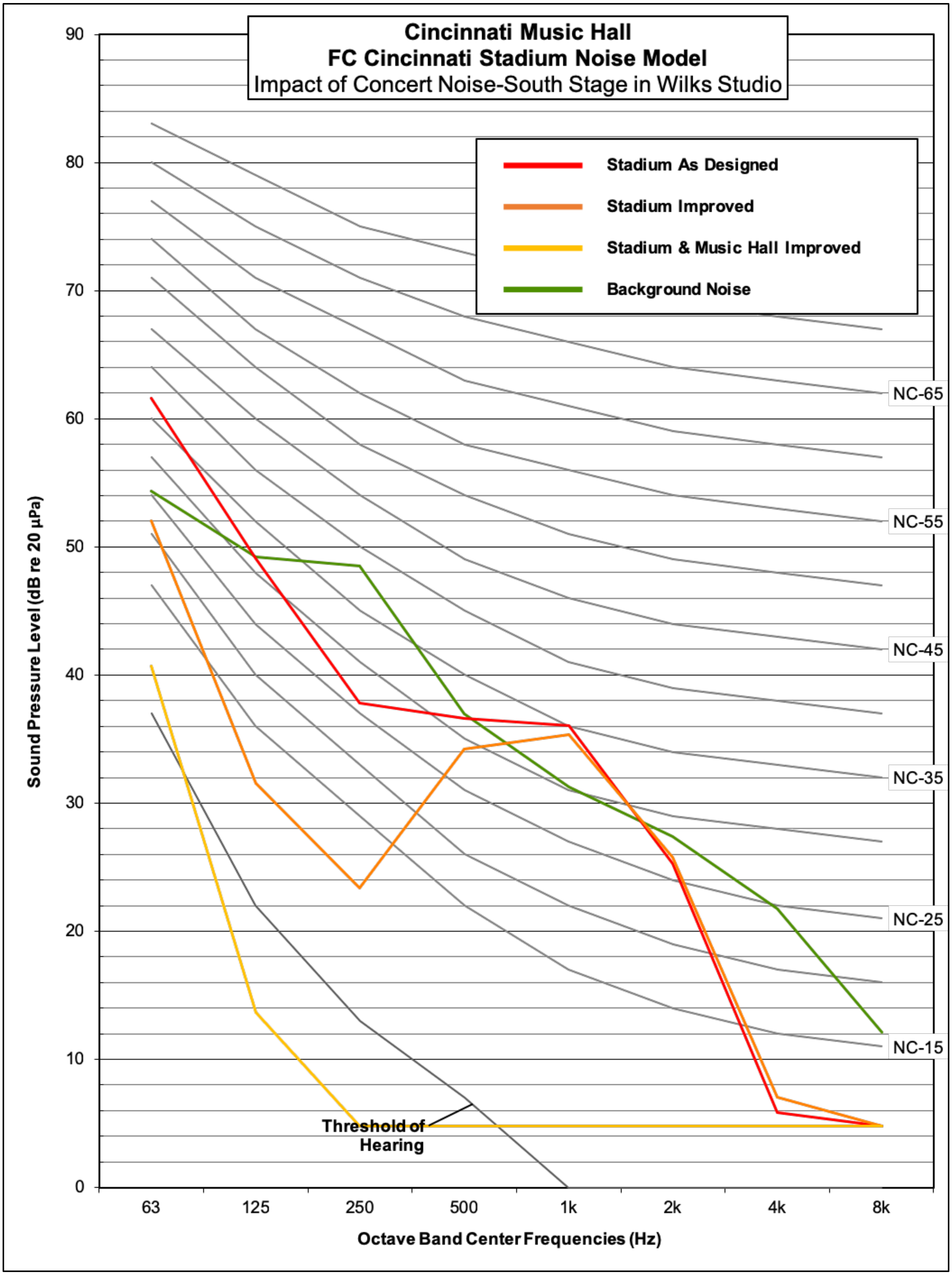
**Graph #12** Scenario A – Crowd Noise and Stadium PA Sound in the Wilks Studio



**Graph #13:** Scenario B – Concert Noise from North Stage in the Wilks Studio



**Graph #14:** Scenario C – Concert Noise from South Stage in the Wilks Studio



## 8.0 Detailed Discussion of the Results: Corbett Tower

8.01 The results for the Corbett Tower suggest that crowd noise and PA system sound from soccer matches would be barely audible in the space. The combination of somewhat better sound isolation characteristics, a higher background noise level and reduced levels due to the distance from, and lack of direct line of sight to the Stadium.

8.02 The results also suggest that high-level amplified contemporary music concerts would only exhibit any intrusion in the low frequency 63 Hz. octave band. Corbett Tower occupants may be aware of the beat associated with concert music in the stadium if Corbett Tower occupants were not making noise of any sort. We do not believe that this intrusion would be disruptive under most circumstances.

8.03 The graphs for the Corbett Tower illustrate two conditions:

a. The red line is the projected level of the scenario inside the Corbett Tower given the current design of the stadium.

b. The orange line is projected level of that scenario inside the Corbett Tower with the reduction achieved by enclosing the stadium seating bowl up to the underside of the stadium roof.

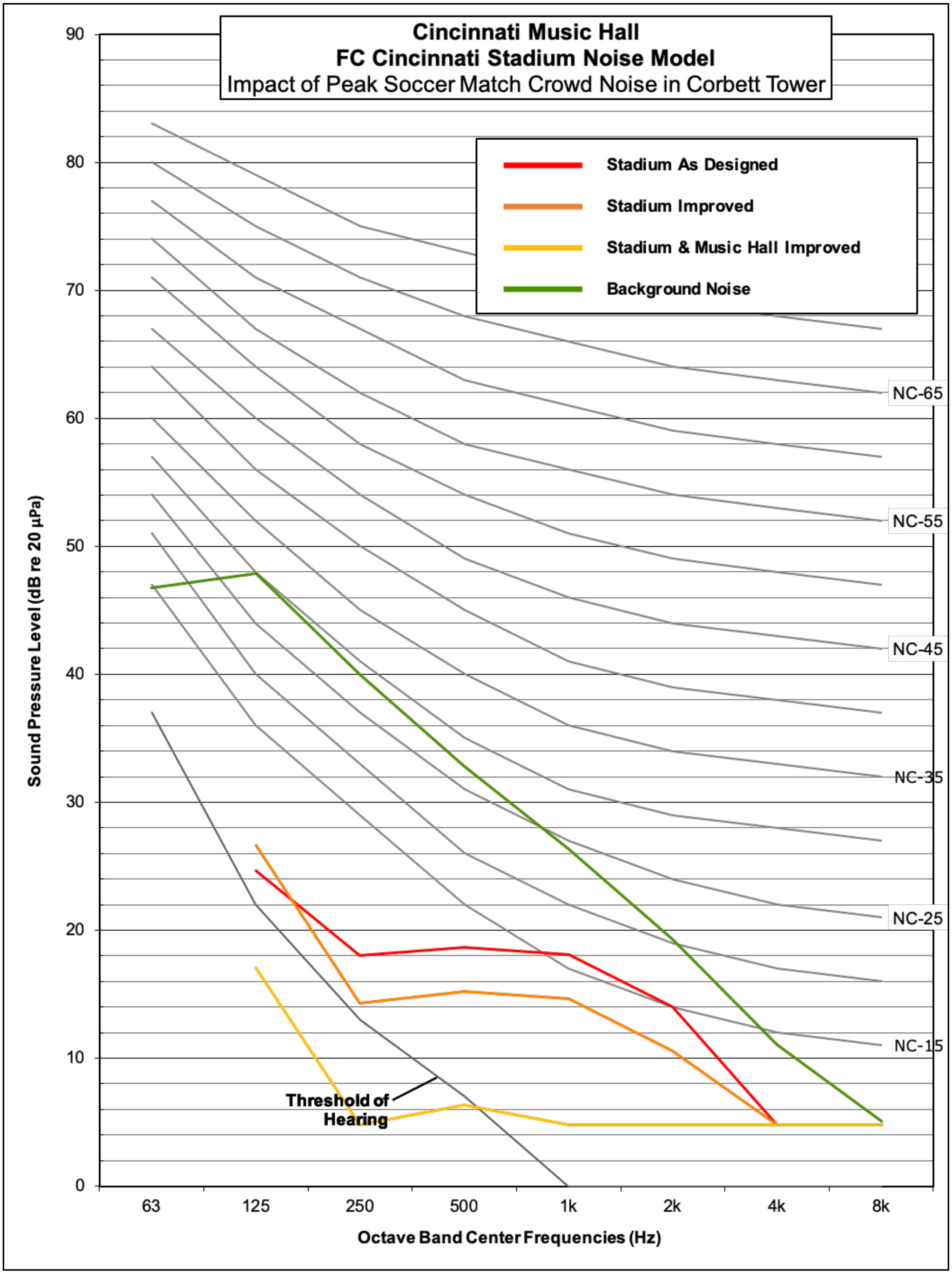
c. The yellow line is the projected level of that scenario inside Corbett Tower with the reduction achieved by enclosing the stadium seating bowl as described above and improving the sound isolation performance of the historic windows by adding an acoustic storm window on the interior of Corbett Tower. The present results suggest that such mitigation is not necessary but further study is suggested to confirm this.

8.04 Graph #15 illustrates the intrusion in Corbett Tower under Scenario A.

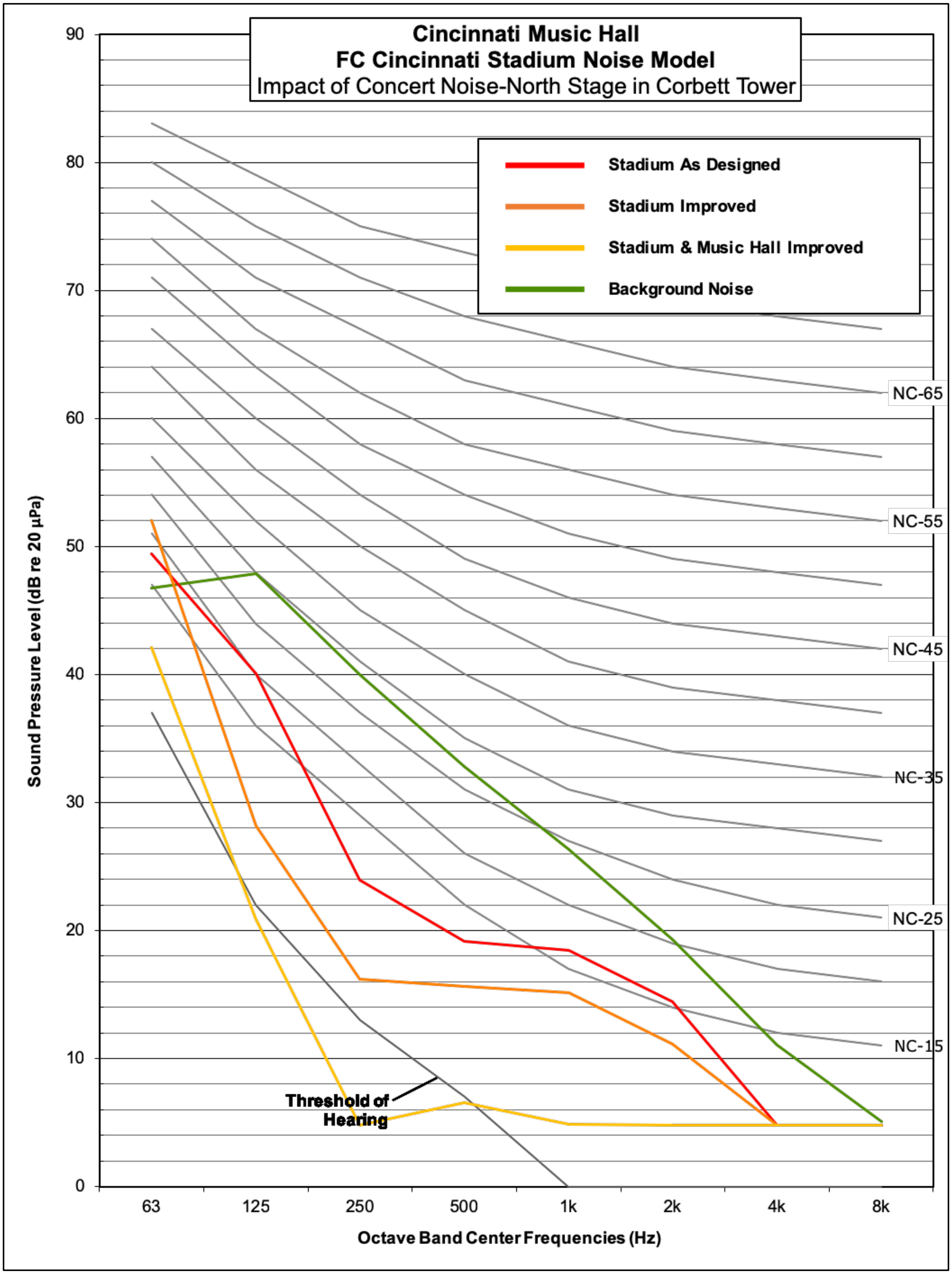
8.05 Graph #16 illustrates the intrusion in Corbett Tower under Scenario B.

8.06 Graph #17 illustrates the intrusion in Corbett Tower under Scenario C.

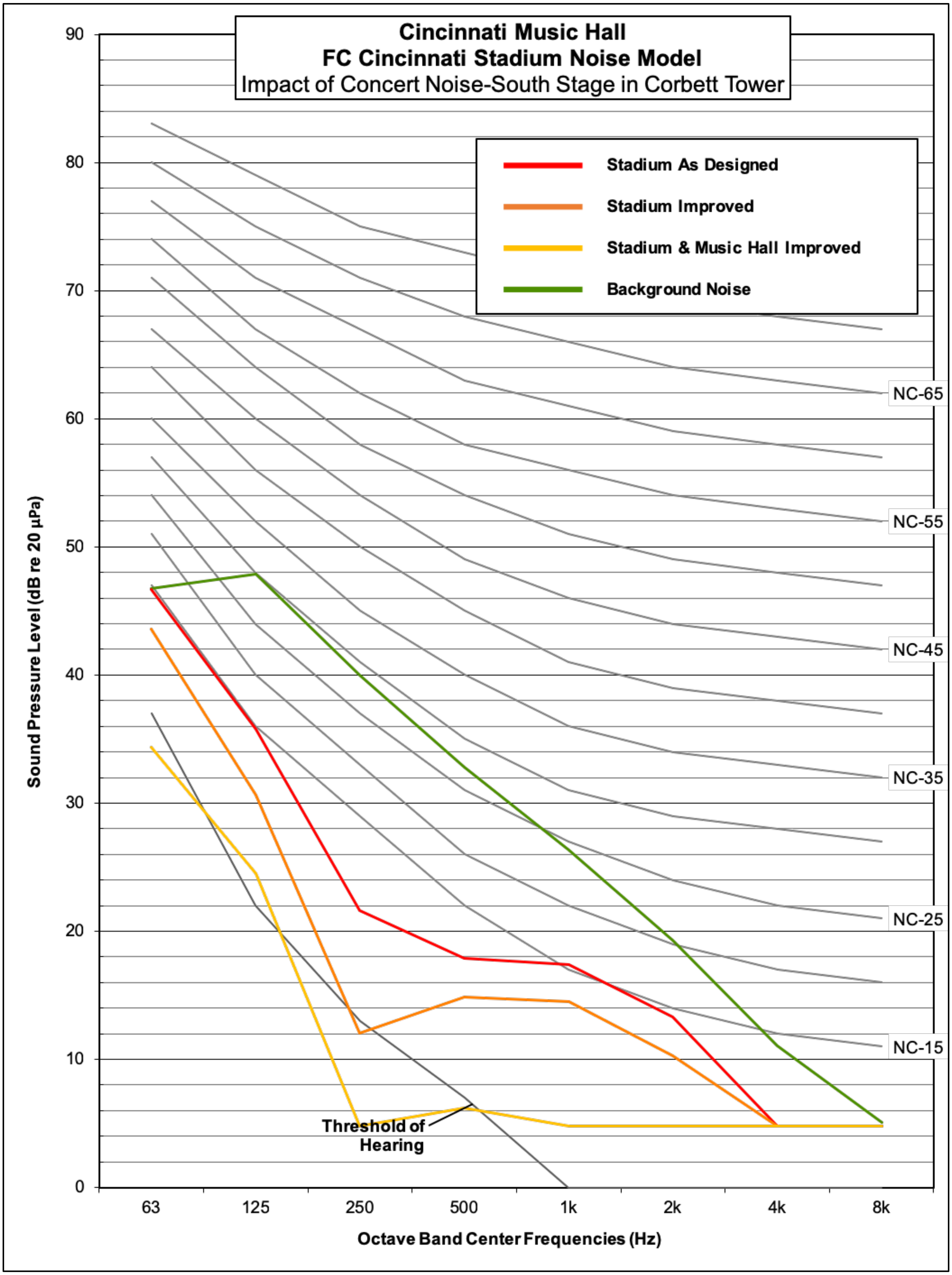
**Graph #15:** Scenario A – Crowd Noise and Stadium PA Sound in the Corbett Tower



**Graph #16:** Scenario B – Concert Noise from North Stage in the Corbett Tower



**Graph #17:** Scenario C – Concert Noise from South Stage in the Corbett Tower



## 9.0 Observations on Noise Propagation from the Stadium

9.01 We examined how sound propagates from the stadium in more detail to lay the groundwork for developing mitigation measures. The key findings are as follows:

a. Although the roof provides some containment of the sound, the opening at the center is large enough to allow a significant amount of sound energy, particularly at low frequencies to escape into the neighborhood.

b. There appear to be significant openings between the underside of the roof and the edges of the seating bowl. These allow a considerable amount of sound to propagate into the neighborhood.

c. The elements around the exterior of the stadium, dubbed “ribbons” by the FC Cincinnati stadium design team, are not continuous and constructed of very lightweight materials. They are essentially ineffective as barriers to noise propagation.

9.02 Graphs #18 through #25 offer a graphical illustration of how sound propagates from the interior of the stadium to the exterior. These are sectional maps taken through the stadium and they show sound levels in color per the legend at the right side of the page. The section cut through the stadium is taken on a diagonal from the northwest corner of the stadium through the southeast corner (see the key plan on the upper right). The cut line continues to an intersection with Music Hall (the large grey series of blocks on the right side of the graphics).

9.03 Graph #18 shows the propagation of sound due to crowd noise. Note how the roof provides some containment of sound but does not control sound emanating through the large opening at the center. Observe how sound also escapes at the top of the seating bowl.

9.04 The next graph down (#19) shows the added impact of the in-house PA system. This is not the actual design for the house PA, as this has not yet been advanced by the design team, but is our best approximation of what such a system would comprise in terms of speaker locations and types. The output of this system is well focused on the seating area and thus minimizes spill outside the stadium. The maximum levels produced by this system at the seating are approximately 90 dBA, which is in line with guidance offered by the FC Cincinnati AV consultant for similar MLS facilities.

9.05 Graph #20 shows the impact of a highly amplified music concert with the stage at the north end of the field facing toward Music Hall. Note how sound diffracts or wraps around the edge of the roof and how it passes through the openings at the top of each section of seating.

9.06 Graph #21 shows the impact of a highly amplified music concert with the stage at the south end of the field facing to the north.

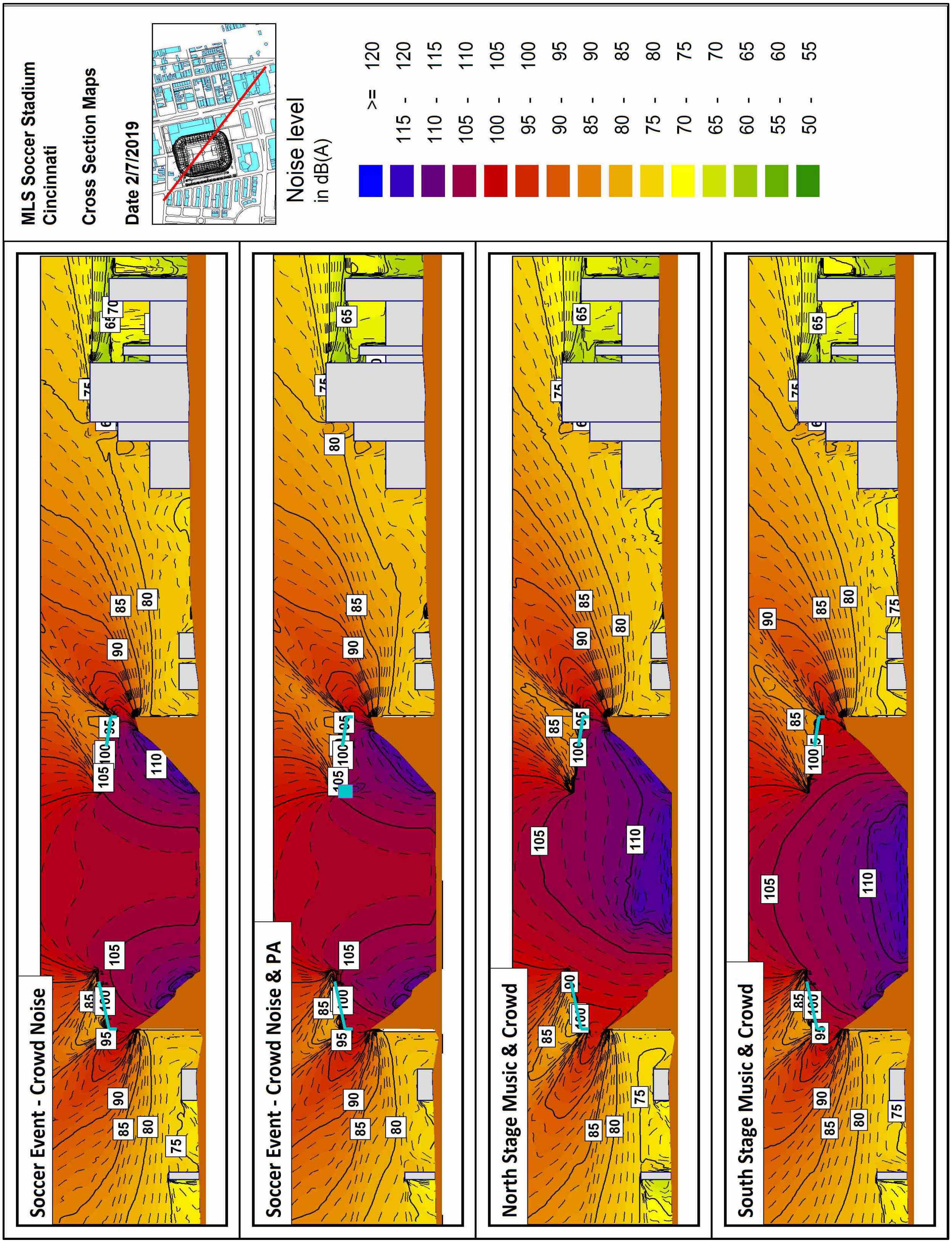
9.07 Graph #22 is the same as graph #18 will the exception that the top of the seating bowl has been closed to the underside of the stadium roof in the model.

9.08 Graph #23 is the same as graph #19 will the exception that the top of the seating bowl has been closed to the underside of the stadium roof in the model.

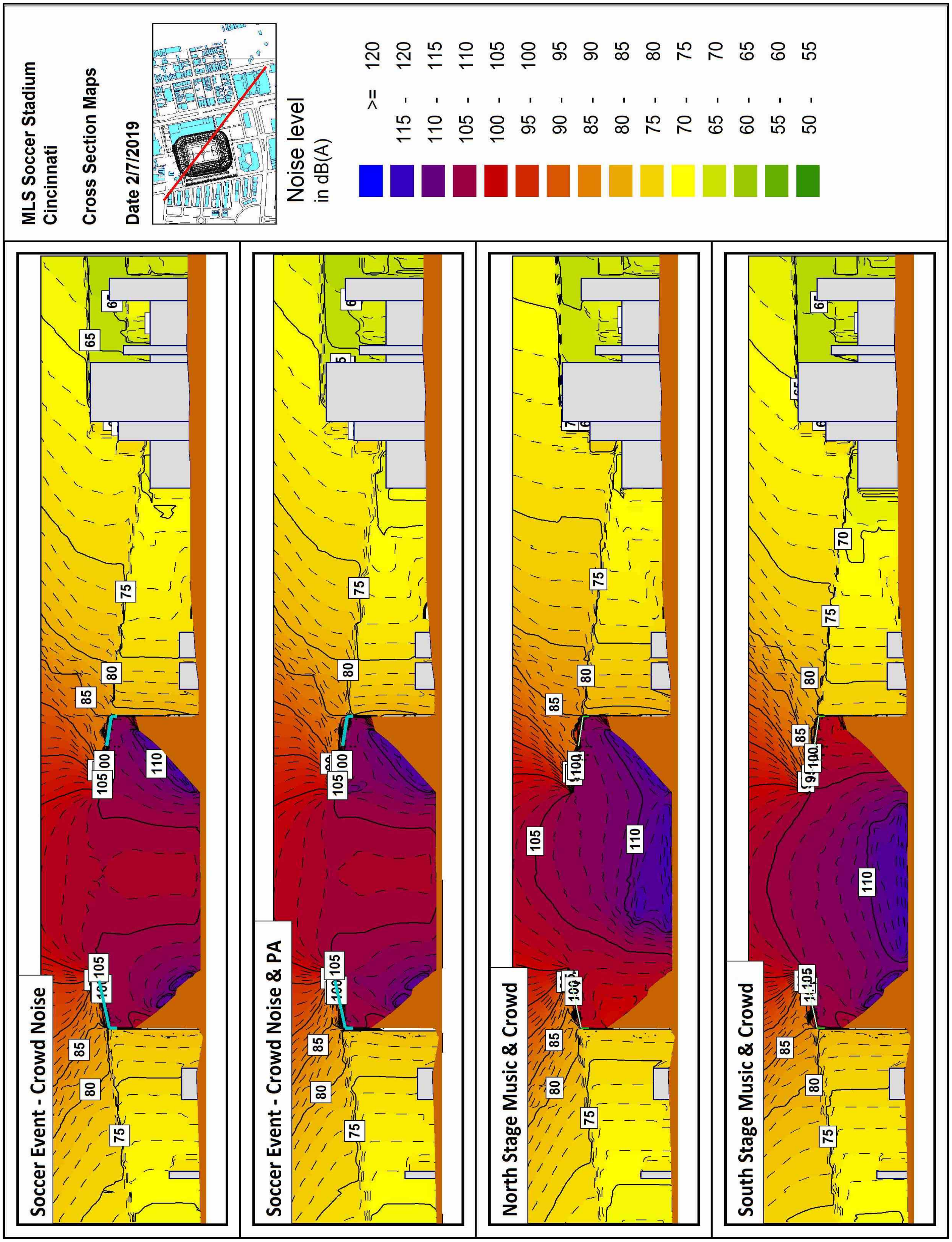
9.09 Graph #24 is the same as graph #20 will the exception that the top of the seating bowl has been closed to the underside of the stadium roof in the model.

9.010 Graph #25 is the same as graph #21 will the exception that the top of the seating bowl has been closed to the underside of the stadium roof in the model.

**Graphs #18, 19, 20 & 21:** Section cut maps through stadium and Music Hall (current stadium design)



**Graphs #22, 23, 24 & 25:** Section cut maps through stadium and Music Hall (revised stadium design)



## 10.0 Commentary about Peak Crowd Noise Levels

10.01 As previously noted, the peak crowd noise levels are based upon an assumption of 75% of the full stadium capacity of 26,000 fans exerting themselves at full vocal output. This figure of 75% or 19,500 people is based upon two assumptions:

a. Even among home town team supporters, some portion of the crowd would not exert themselves at a peak level of effort, and,

b. Some portion of the crowd would be supporting the visiting team and thus would react at different moments of the match than would the home team crowd.

10.02 Even if only a significantly smaller percentage of the crowd express themselves at peak vocal effort, the impact at Music Hall could still be significant. For example, if only half of our theoretical 75% of the crowd (or 37.5% of the total stadium capacity or 9,750 fans) employed peak vocal effort, theory tells us that the resultant sound pressure levels at Music Hall would only fall by 3 dB. Such levels would still produce an intrusion in Springer Auditorium that is well above the background noise in the auditorium and clearly audible during the quiet moments in a performance. Another halving of the crowd exerting themselves at peak vocal effort to 18.75% of capacity or 4,875 people would result in another 3 dB reduction in the levels projected at Music Hall. The model predicts that even these levels would produce a measurable and audible intrusion in Springer Auditorium.

10.03 Since it is not possible to predict the number, duration or timing of peak crowd noise events during a match, any suggestion that such events would be few in number and thereby be of little consequence to performances in Music Hall ignores the fact that much of the music in the Western symphony, opera and ballet canon employs a broad dynamic range and that some of the most dramatic and moving moments in such music occur at the edges of silence. If an intrusion of stadium crowd noise occurred during one of these quiet passages, the magic of that moment would be destroyed and the enjoyment of the audience significantly impaired.

## 11.0 Limitations

11.01 It is important to recognize that the environmental noise model employed in this study is limited by the accuracy of the underlying data used to model key aspects of the FC Cincinnati Stadium and its environs:

a. The sound isolation properties of certain assemblies (e.g., Lexan roof panels) have been predicted using industry standard software. As with any predictive tool, there is a measure of uncertainty associated with these results.

b. The sound isolation properties of certain assemblies (e.g., the metal roof panels) have been drawn from published manufacturer literature. These properties are only as reliable as the underlying tests

c. The propagation of sound in the outdoors can be influenced by a number of factors including wind, temperature, and humidity. The complexity and variability of these factors cannot be modelled with accuracy.

11.02 Acknowledging the foregoing, we believe it is reasonable that the results of this study be considered to have a margin of error of ±5 dB.

## 12.0 Mitigation Strategies

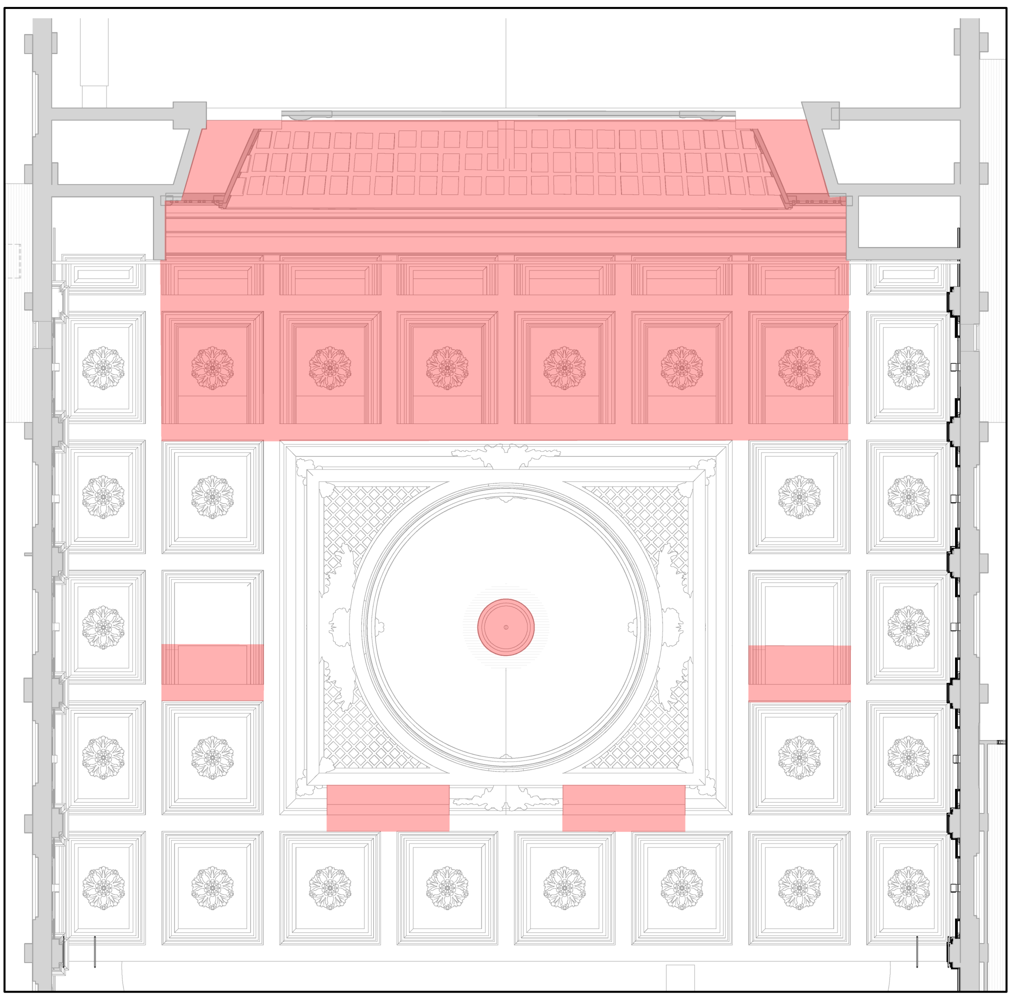
12.01 As noted previously, we believe that there are mitigation strategies that can be employed to address the impacts that FC Cincinnati Stadium would have on the various spaces in Music Hall. Successful implementation of these measures should allow both Music Hall and the new FC Cincinnati to coexist in the West End.

12.02 In Springer Auditorium, the proposed mitigation strategies involve refinements to the design of the stadium as well as changes within the attic of Music Hall.

a. The refinement to the design of the FC Cincinnati Stadium would comprise closing up openings between the seating bowl and the underside of the roof to eliminate the leakage sound below the roof. While we are not recommending specific materials for these enclosing elements, the model assumed that they would achieve of uniform insertion loss of 15 dB across the frequency spectrum.

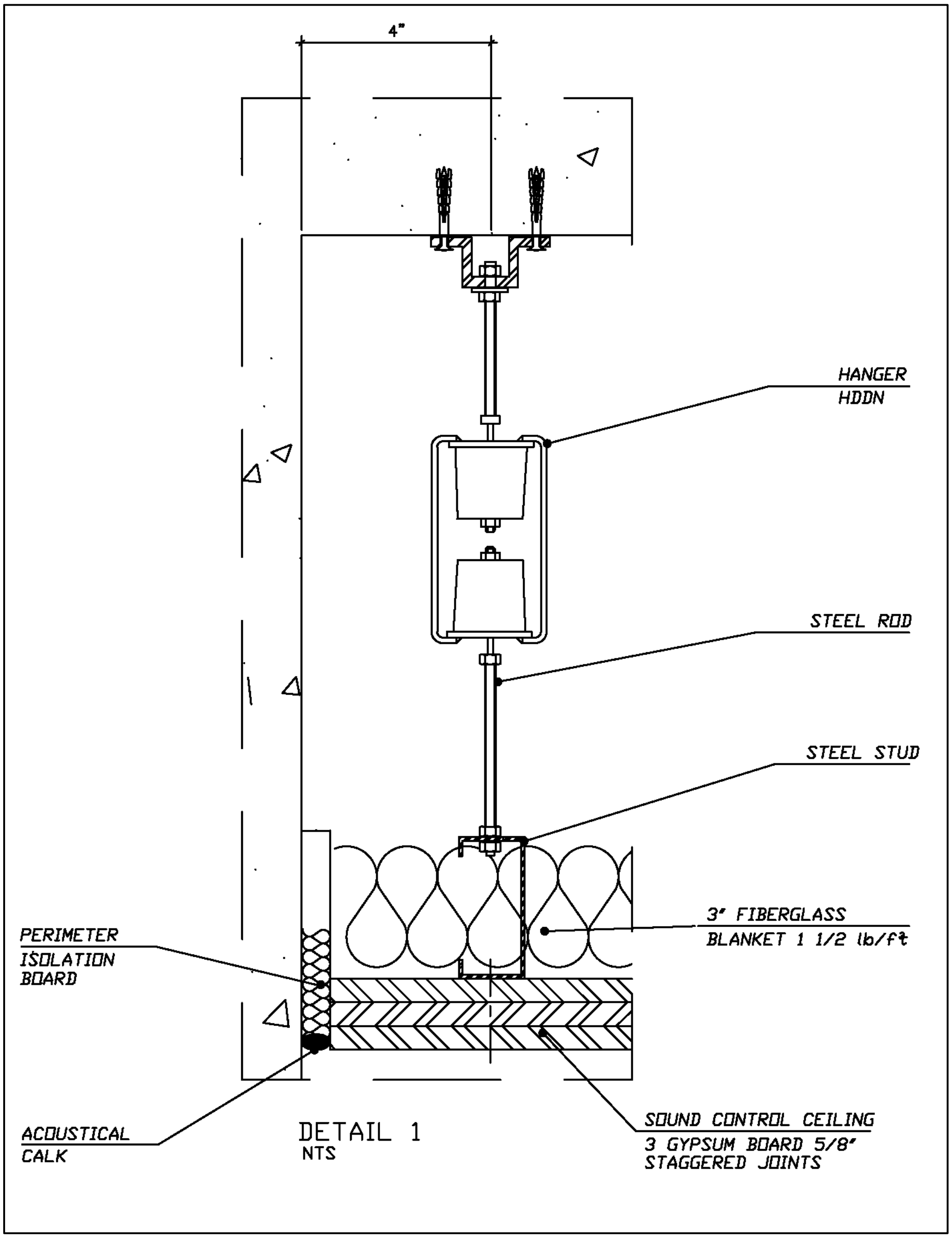
b. Within Springer Auditorium, we believe that the most promising course of action would comprise adding enclosures around the existing front-of-house lighting positions, rigging openings and chandelier exhaust to segregate these areas from the attic. The areas involved are shown in the reflected ceiling plan below.

**Illustration 1:** Reflected ceiling plan of Springer Auditorium showing preliminary locations for enclosures.



c. The alternate to the above scheme would involve the installation of a multi-layer gypsum board isolation ceiling on the underside of the attic roof over Springer Auditorium. This assembly is shown in the illustration below.

**Illustration 2:** Conceptual sketch of a sound isolation ceiling




d. It may also be necessary to upgrade the isolation through the roof over the stage in Springer Auditorium. Further study and assessment of its sound isolation properties is necessary to determine this.

12.03 In the May Festival Chorus Rehearsal Room, it appears that the stadium mitigation strategy described in Section 10.01 above would be sufficient to mitigate the impacts from non-sporting

events (concerts) in this space. Further mitigation does not appear to be warranted under the assumption that the stadium mitigation is required to address the issues in Springer Auditorium.

12.04 In the Ballroom, no mitigation is anticipated to be necessary.

12.05 In the Wilks Studio, mitigation will require improvements to the Stadium design and improvements to Studio itself. This mitigation measures for the Wilks Studio would involve:

a. It will be necessary to construct isolated drywall assemblies at the exterior wall to improve the sound isolation performance of the existing wall. These assemblies would comprise stud framing that is supported neoprene partition supports and set off the face of the existing brick using neoprene sway braces. The interior side of the stud framing would be faced with 2-layers of 5/8-inch thick Type X drywall. The cavity would be approximately 8-inches deep and would be filled with mineral wool insulation. To preserve access to natural light, the new isolated drywall partition would require ¾-inch thick laminated glass windows sized to match the existing exterior windows.

b. It will be necessary to construct an isolated drywall ceiling under the roof in the studio to improve the sound isolation performance of the existing roof (see Illustration 1). This assembly would comprise metal framing that is supported on neoprene-spring isolation hangers and faced with 2-layers of 5/8-inch thick Type X drywall.

12.06 In Corbett Tower, it appears that mitigation beyond what is proposed for the Stadium may not be required. If mitigation is desired, we believe that it could be as simple as adding ¾-inch thick acoustic storm windows to the interior of the existing historic windows.

## 13.0 Pyrotechnics

13.01 The environmental noise model has not considered the impact of pyrotechnics on the various space in Music Hall. The nature of pyrotechnic displays and their acoustic output can vary substantially in both frequency content and overall sound pressure levels. Some sizes and types of pyrotechnics would produce levels that would exceed even the levels associated with highly amplified contemporary music concerts. We do not believe that it would be prudent to attempt to mitigate these impacts through improvements to the building envelope at Music Hall. We therefore recommend that the use of pyrotechnics be controlled, limited or prohibited during events in Music Hall.

## 14.0 Conclusions

14.01 The Environmental Noise Model for the planned FC Cincinnati Stadium indicates that normal stadium operations (soccer matches) and non-sporting uses (amplified concerts) will have a significant impact on Music Hall and its various performance and rehearsal venues. Current modelling indicates that these impacts will be sufficient to require mitigation.

14.02 The strategies necessary to mitigate the impacts from normal stadium operations and non-sporting uses of the venue involve improvements to the stadium design to better contain event noise as well as improvements to the sound isolation properties of selected portions of the Music Hall structure.

## Appendix - Tabular Data

Third Octave Band Noise Reduction Values Derived from Shotgun Testing

| dB ref 20µPa | 31.5 | 40 | 50 | 63 | 80 | 100 | 125 | 160 | 200 | 250 | 315 | 400 | 500 | 630 | 800 | 1k | 1.25k | 1.6k | 2k | 2.5k | 3.15k | 4k | 5k | 6.3k | 8k | 10k |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Springer | 36 | 39 | 41 | 42 | 43 | 44 | 41 | 37 | 42 | 45 | 47 | 49 | 47 | 45 | 58 | 52 | 59 | 57 | 45 | 50 | 47 | 54 | 69 | 70 | 64 | 68 |
| Chorus | 35 | 39 | 34 | 32 | 38 | 42 | 37 | 41 | 47 | 55 | 52 | 56 | 56 | 57 | 61 | 61 | 74 | 73 | 66 | 76 | 80 | 77 | 70 | 68 | 66 | 70 |
| Ballroom | 34 | 32 | 38 | 37 | 35 | 38 | 36 | 41 | 44 | 51 | 51 | 55 | 54 | 51 | 60 | 58 | 71 | 64 | 59 | 69 | 66 | 70 | 67 | 67 | 65 | 71 |

Third Octave Band Sound Pressure Levels Projected at Music Hall Roof – Soccer Match

| dB ref 20µPa | 31.5 | 40 | 50 | 63 | 80 | 100 | 125 | 160 | 200 | 250 | 315 | 400 | 500 | 630 | 800 | 1k | 1.25k | 1.6k | 2k | 2.5k | 3.15k | 4k | 5k | 6.3k | 8k | 10k |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Springer | | | | | | 56 | 60 | 59 | 56 | 57 | 57 | 57 | 61 | 64 | 63 | 63 | 65 | 62 | 57 | 55 | 50 | 45 | 33 | 26 | 15 | 0 |
| Chorus | | | | | | 55 | 59 | 56 | 53 | 53 | 53 | 53 | 57 | 61 | 60 | 61 | 62 | 60 | 54 | 52 | 48 | 44 | 33 | 26 | 18 | 4 |
| Ballroom | | | | | | 53 | 57 | 55 | 53 | 53 | 52 | 52 | 56 | 59 | 58 | 58 | 59 | 56 | 49 | 46 | 40 | 34 | 21 | 11 | - | - |

Third Octave Band Sound Pressure Levels Projected at Music Hall Roof – Concert Event-North Stage

| dB ref 20µPa | 31.5 | 40 | 50 | 63 | 80 | 100 | 125 | 160 | 200 | 250 | 315 | 400 | 500 | 630 | 800 | 1k | 1.25k | 1.6k | 2k | 2.5k | 3.15k | 4k | 5k | 6.3k | 8k | 10k |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Springer | 76 | 75 | 74 | 85 | 71 | 71 | 68 | 61 | 60 | 61 | 60 | 58 | 61 | 64 | 64 | 64 | 66 | 63 | 57 | 56 | 51 | 46 | 35 | 27 | 16 | 0 |
| Chorus | 72 | 69 | 67 | 81 | 55 | 66 | 62 | 54 | 54 | 55 | 55 | 53 | 58 | 61 | 61 | 61 | 63 | 60 | 55 | 53 | 49 | 45 | 34 | 27 | 19 | 4 |
| Ballroom | 73 | 73 | 68 | 75 | 66 | 74 | 68 | 62 | 58 | 53 | 51 | 52 | 55 | 58 | 57 | 57 | 58 | 55 | 48 | 46 | 40 | 34 | 21 | 12 | 0 | 0 |

Third Octave Band Sound Pressure Levels Projected at Music Hall Roof – Concert Event-South Stage

| dB ref 20µPa | 31.5 | 40 | 50 | 63 | 80 | 100 | 125 | 160 | 200 | 250 | 315 | 400 | 500 | 630 | 800 | 1k | 1.25k | 1.6k | 2k | 2.5k | 3.15k | 4k | 5k | 6.3k | 8k | 10k |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Springer | 64 | 66 | 73 | 66 | 71 | 67 | 48 | 46 | 52 | 53 | 54 | 55 | 60 | 64 | 63 | 63 | 64 | 62 | 56 | 54 | 49 | 44 | 32 | 23 | 11 | 0 |
| Chorus | 65 | 67 | 70 | 66 | 67 | 63 | 44 | 40 | 48 | 49 | 51 | 51 | 57 | 60 | 60 | 60 | 62 | 59 | 53 | 52 | 47 | 42 | 31 | 24 | 13 | 0 |
| Ballroom | 60 | 43 | 63 | 77 | 65 | 73 | 68 | 61 | 61 | 53 | 52 | 50 | 55 | 58 | 57 | 57 | 58 | 55 | 49 | 46 | 40 | 33 | 19 | 8 | 0 | 0 |